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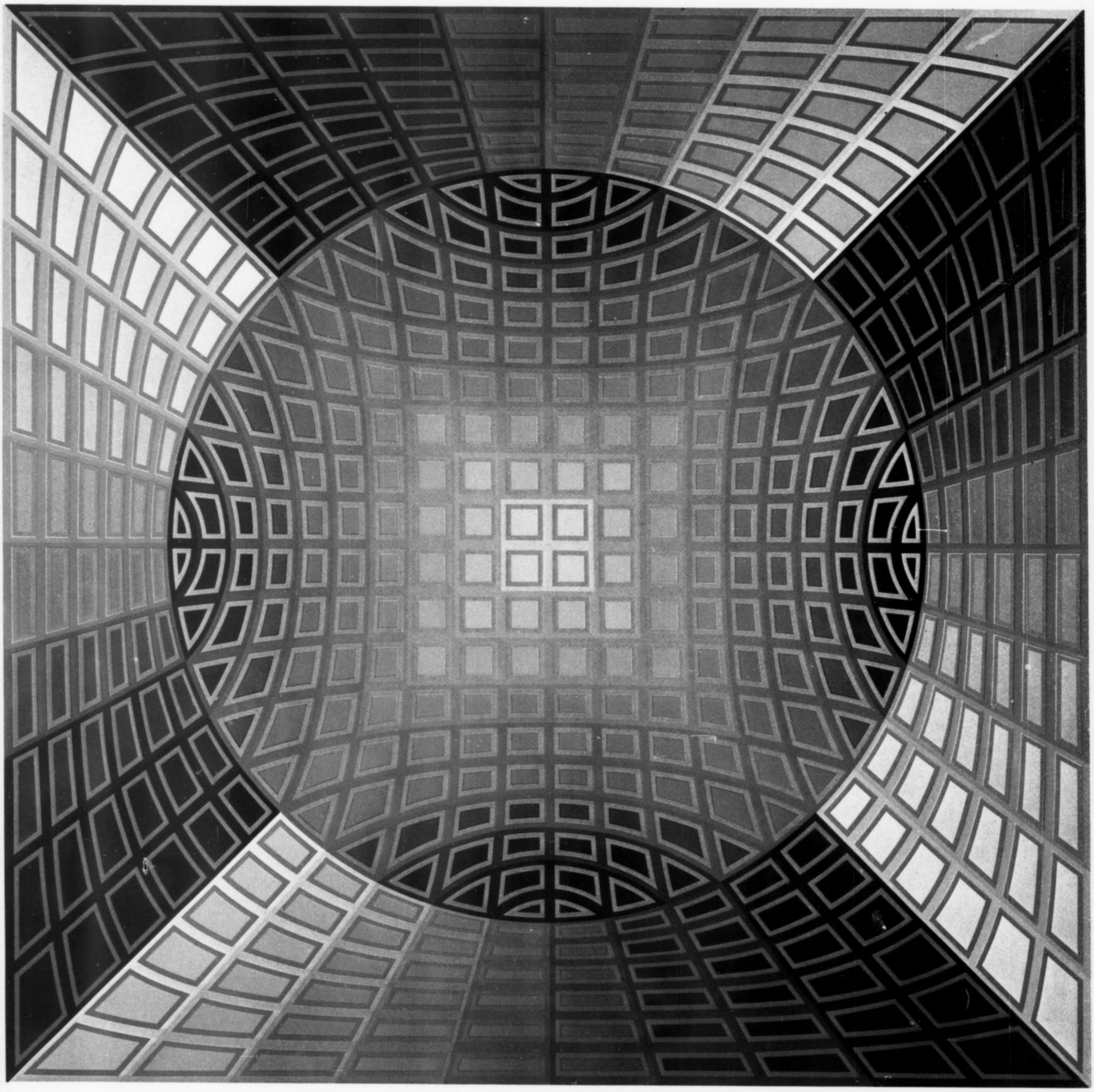
open on the world



Einstein

Photo René Roland © Ziolo, Paris

TREASURES
OF
WORLD ART

142

India

The smiling boy

This head of a smiling boy is an example of early Indian art dating from some time during the Maurya (322-185 BC) or Sunga (185-72 BC) periods. The boy is portrayed wearing a two-cornered head-dress gracefully swathed in cloth. Fashioned in terra cotta which still bears traces of colour, the head (12 cm high) is now in the Museum of Patna, capital of Bihar state in northern India.

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Page

4 **ALBERT EINSTEIN 1879-1955**
The story of a genius
by Jürgen Ehlers

9 **RELATIVITY IN A NUTSHELL**
by Isaac Asimov

10 **EINSTEIN'S TOPSY-TURVY UNIVERSE**

17 **THE TEST OF TIME**
by Paul Dirac

18 **LIGHT CAUGHT BENDING**
Photo story

24 **THE MOLE AND THE BUTTERFLY**
Reflections on Einstein, science and subjectivity
by Pierre Thuillier

26 **A CONSTELLATION OF COSMOLOGISTS**

29 **THE FRONTIERS OF SCIENCE**
by Arkadii Migdal

31 **THE SCIENTIST'S DILEMMA**
by Albert Einstein

2 **TREASURES OF WORLD ART**
INDIA : The smiling boy

I-IV **NEWS FROM UNESCO**
Special supplement

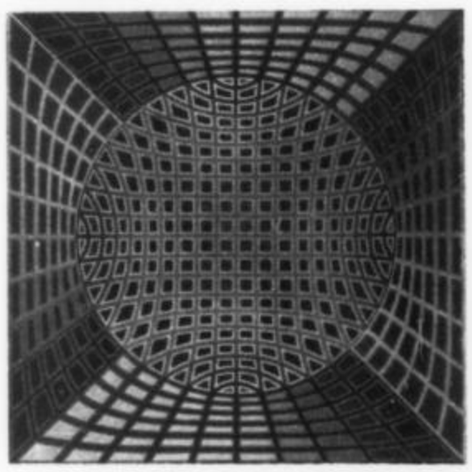


Photo © Anne Desailly, Paris

Cover

Art pays tribute to science in the dazzling curves of "space-time" which sweep across Victor Vasarely's painting *Einstein* (1976). The work symbolizes the genius of the great physicist, born a hundred years ago, who opened up a new age in science. The reach and brilliance of his work, especially his theories of relativity, were such that the full implications of his thought are still being explored. Einstein's deeply-felt humanism and lovable personality also profoundly marked his epoch.

Albert Einstein

1879-1955

The story of a genius

by Jürgen Ehlers

ACCORDING to the eighteenth-century German romantic poet and science-enthusiast Novalis, "theories are nets: only he who casts will catch". Using this metaphor one can say that no fisherman in this century was more successful than Albert Einstein.

In his *annus mirabilis,* 1905, comparable in the history of science perhaps only to the memorable year 1666 when Isaac Newton conceived most of the ideas which were to govern science for more than two hundred years, Albert Einstein published in one and the same volume of the German scientific journal *Annalen der Physik* three papers each of which, besides containing important specific results, laid the ground for extensive new areas of fundamental research.

Who was this man Albert Einstein who, as a twenty-six-year-old technical expert, third class, at the Swiss patent office in Berne, invented in his spare time new methods in statistical mechanics, discovered light quanta, gave a proof of the existence of atoms, solved the problem of constructing a correct electrodynamics of moving bodies, a problem attacked without definitive success by leading scientists of the time like Hendrik Anton Lorentz and Henri Poincaré, by setting up a new theory of space and time?

Albert Einstein was born on 14 March 1879, in Ulm, Germany, in the same year in which Max von Laue and Otto Hahn were born and James Clerk Maxwell, the founder of the modern theory of electromagnetic fields, died.

The Einsteins were Jews, but did not follow the rituals and laws of the Jewish religion any more. In 1880 the family moved to Munich, where Albert's father Hermann ran a small electrochemical factory with his brother. In the same year Albert's sister Maja, his only sibling, was born. The young Albert has been described as a taciturn, pensive, day-dreaming little boy,. slow at learning to speak, not liking physical activities or playing much with other children.

When he was four or five years old, Albert Einstein experienced, according to his recollection, what appeared to him as a miracle. A magnetic compass, shown to him by his father, appeared to be drawn steadfastly and by a mysterious, invisible power, always into the same direction, irrespective of how one moved the housing of the compass.

Does this deep impression, vividly remembered after many years, indicate a longing for something dependable, something which the young as well as the mature Einstein did not find in the human world surrounding him, but which he did find in the unchanging, impersonal structure of nature?

Albert attended a Catholic elementary school, and at the age of ten entered the Luitpold Gymnasium. He disliked the strict discipline, the authoritarian spirit, the lack of freedom at the gymnasium, where he had to learn Latin and Greek grammar which interfered with his studies of mathematics and science, the interest in which had been excited in him by his uncle who was an engineer.

Unhappy and depressed, an ill-adapted outsider, considered by his teachers as having a disruptive influence on his classmates, Albert Einstein soon followed his parents, without a school diploma, to Milan where they had moved in 1894 because of business difficulties. After one year of studies at a school at Aarau in Switzerland where he felt much happier, Albert Einstein was admitted as a student of mathematics and physics to the famous Polytechnic Institute in Zurich.

Among his fellow students were Mileva Maric, a Serbian girl who in 1902 became his first wife and who was to be the mother of his two children, and Marcel Grossmann, who eighteen years later became his mathematical collaborator.

JURGEN EHLERS, *noted German theoretical physicist, is a Scientific Member of the Max Planck Institute of Physics and Astrophysics at Munich (Federal Republic of Germany).* *This article is an edited and abridged version of a lecture given at Munich University in September 1978, at a Unesco symposium on the Impact of Modern Scientific Ideas on Society.*

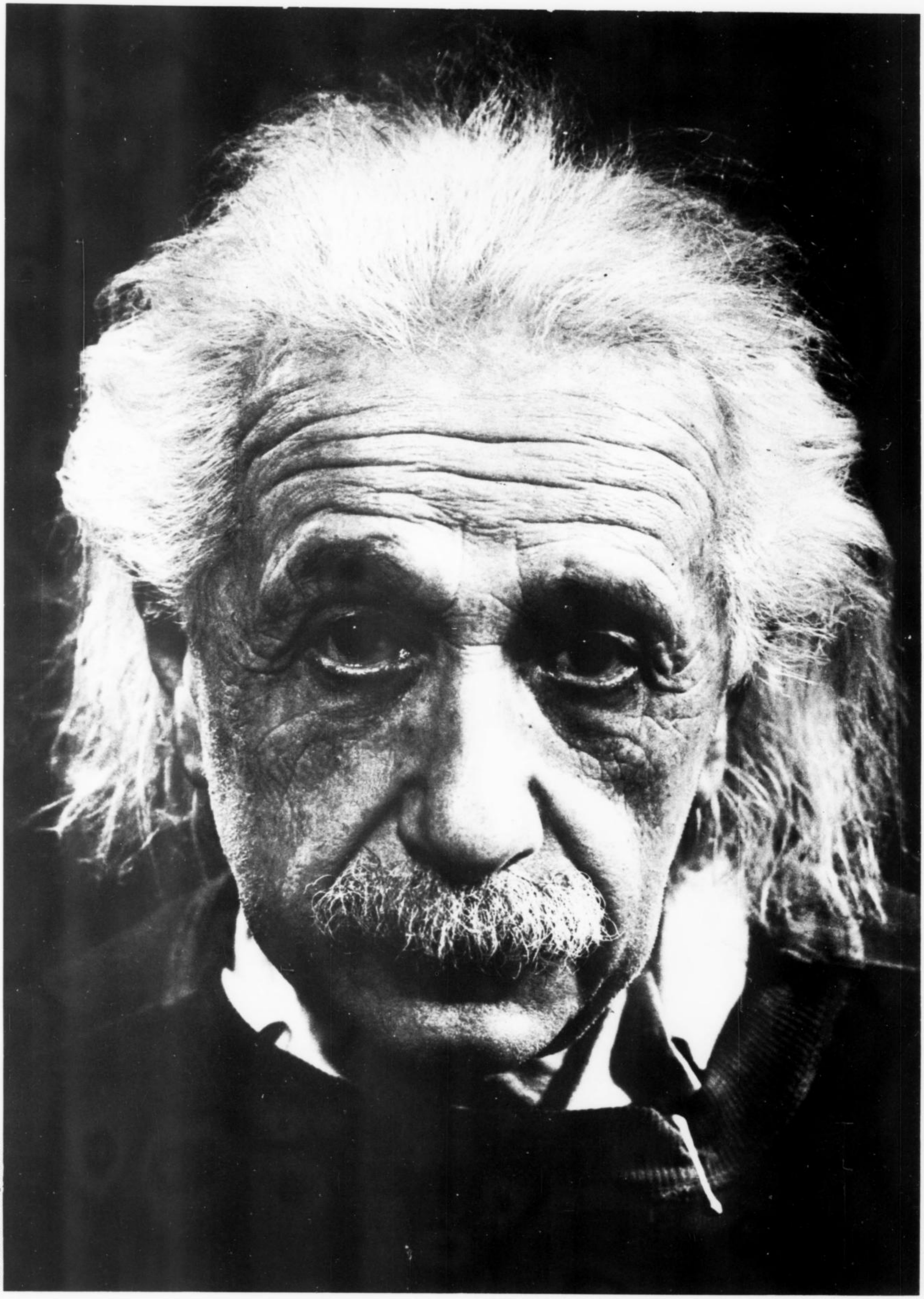


Photo Halsman © Magnum, Paris

Among his teachers was the outstanding mathematician Hermann Minkowski, who in 1907 invented the concept of space-time and thus contributed in an essential way to the development of the theory of relativity.

After graduation in 1900 Einstein failed to obtain a position at the Polytechnic or as a teacher, but in 1902, with the help of his friend Marcel Grossmann, he got a post at the Patent Office in Berne. Here he prepared himself for the examination for his doctor's degree which he took in 1905, and found enough time to pursue his research in theoretical physics.

Einstein kept the position in Berne until the end of 1909 when he accepted his first full-time academic appointment as associate professor at the University of Zurich. His accomplishments had by then been widely recognized. He had extended his research on the agitation of microscopic particles known as Brownian motion, on light quanta and relativity. He had created the first quantum theory of specific heats of solids; and, in 1907, he had formed the opinion that a satisfactory theory of gravitation would have to incorporate in a basic and natural way the equality of inertial and gravitational mass, and the fact, already noted by Galileo, that all test bodies fall with the same acceleration.

Gravity and inertia are essentially the same thing, Einstein decided, and therefore a satisfactory theory of gravity required a generalization of the space-time framework of his theory of relativity, for if gravity is taken into account the concept of a finitely extended, strict inertial frame of reference is no longer adequate.

In 1910 Einstein accepted a full professorship at the German University of Prague. For the reasons just indicated Einstein was searching for a generalization of what he now called the "special theory of relativity", in order to include gravitation.

Gravitation theory was his main concern between 1907 and 1916. Whereas the majority of physicists had by then accepted special relativity as a solid part of the building of physics, Einstein was occupied with finding out its limits of validity and struggled for a more inclusive and more precise mathematical representation of physical processes. In Prague, in 1911, he arrived at the prediction that light waves are bent by gravitational fields, but not until 1914 was an expedition ready to make appropriate observations during a solar eclipse. The First World War ruled out this attempt, and the first measurement had to wait until 1919.

After eighteen months in Prague, at the end of 1912, Einstein returned to Zurich, this time to become a full professor at the Polytechnic Institute where he had studied a dozen years before.

In Zurich, in collaboration with his friend Marcel Grossmann who had become a professor of mathematics, Einstein published a preliminary version of a new theory of gravity.

At the end of 1913, on the initiative of

Photo © Ullstein, Fed. Rep. of Germany

Albert Einstein at the age of four. He was far from being a precocious child and did not begin talking until he was three years old. Later, his mother wrote anxiously to a friend : "I really don't know what we shall make of Albert later on; he learns next to nothing".

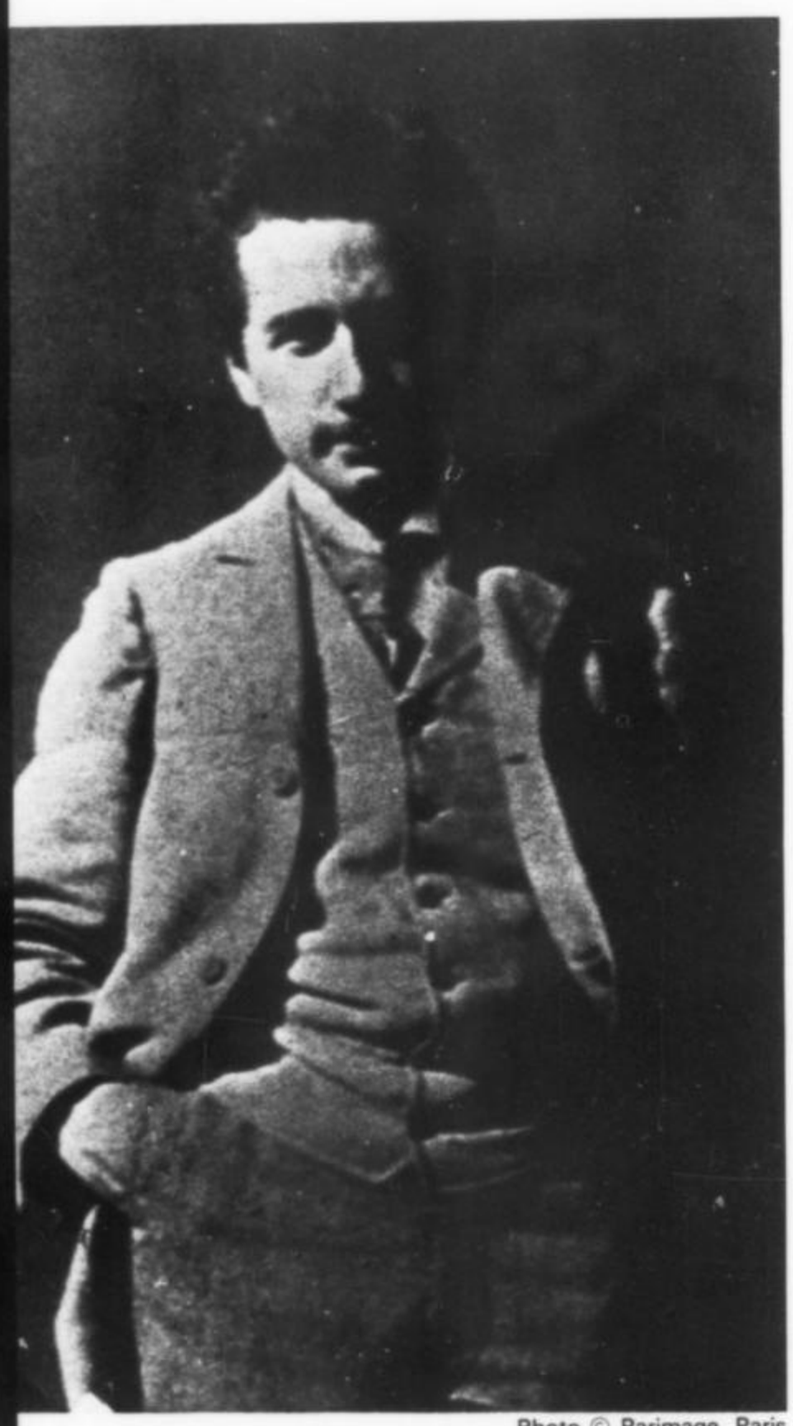


Photo © Parimage, Paris

One of the few surviving pictures of Einstein as a young man. It was taken when he was a pupil at the Polytechnic Institute in Zurich in 1900, five years before the publication of the great paper in which he set forth the special theory of relativity.

the German physicists Max Planck and Walter Nernst, Einstein was offered a well-paid position as a member of the Royal Prussian Academy of Sciences in Berlin and director of the yet-to-be-founded Kaiser-Wilhelm Institut für Physik.

His duty was to be the organization of research. He was not obliged to teach, but could do so if he wanted. Einstein had always considered formal teaching a burden, and he was attracted to the lively scientific atmosphere of Berlin. So he accepted the offer. Soon after his arrival in Berlin he separated from his wife Mileva. Einstein was now thirty-four years old and a star of the first magnitude in the sky of science.

In Berlin, in spite of many contacts with colleagues, in particular with Max Planck, Max von Laue, Walter Nernst and later Erwin Schrödinger, and many others, Einstein felt somewhat isolated and a foreigner. He did not lecture, but participated actively in the discussions following colloquia. Being a pacifist and opposed to nationalism, he felt even more isolated during the First World War.

He now concentrated fully on the theory of gravitation and after a strenuous effort Einstein succeeded at the end of 1915 in formulating a coherent theory which is still considered as the most admirable part of classical physics. This theory has come through all experimental tests performed up to now with flying colours.

In 1917, in a paper which is regarded as his most important contribution to quantum theory, Einstein proposed a statistical description of the interaction of atoms and photons and gave a new derivation of Planck's law of radiation, which had laid the foundations of quantum theory. In the same year Einstein founded modern cosmology, the science of the large-scale structure of the universe, by constructing the first mathematically consistent model of the universe containing gravitating, homogeneously distributed matter.

During the years 1921, 1922 and 1923 Einstein travelled in the United States, Europe and Asia. Convinced by Chaim Weizmann, he engaged himself for the Zionist movement. In 1921 he was awarded the Nobel prize, not for his relativity theory, but "for the photoelectric law and his works on theoretical physics".

When Hitler came to power in 1933, Einstein was travelling in the United States. He never again entered Germany. After a short stay in Belgium, during which he resigned from the Prussian Academy and the Bavarian Academy of Sciences in protest against the passive attitude taken by these academies when academic freedom was suppressed in Germany and many scientists and intellectuals were removed from their positions for "ideological reasons", Einstein accepted a position at the newly founded Institute for Advanced Study in Princeton (U.S.A.). He continued research, concentrating mainly on the creation of what he called a unified field theory which would, so he hoped, give a deeper account of both gravity and electromagnetism, and in addition would describe particles as stable regions of high concentration of the field. In these efforts Einstein did not succeed, but in a modified form his programme of using geometry to create such a unified theory has received a strong new impetus and has had considerable success in recent years.

Besides these efforts Einstein occasionally returned to his gravity theory of 1915 and enriched it by new results. In 1932, he collaborated with the Dutch astronomer Willem de Sitter to construct a model of an expanding universe which is still a possible candidate to represent the large-scale structure of the material world. Joint work with Nathan Rosen in 1937 resulted in solutions of his field equations which describe gravitational waves, and a celebrated paper published in 1938, written with Banesh Hoffmann and Leopold Infeld, was devoted to the derivation of equations of motion of particles from the gravitational field equations. The subject of this paper is still under discussion. Research on it is being carried out by, among others, my collaborators and myself at the Max Planck Institut für Physik und Astrophysik, at Munich (Federal Republic of Germany).

Even after his retirement in 1945 Einstein continued to work right up to his death on 18 April 1955, at the age of seventy-six.

One important characteristic of Einstein's approach to basic problems of physics was that he questioned the adequacy of even those concepts and relations which were generally regarded as evident; in this sense he was a philosopher.

According to Einstein, concepts are free inventions, and the axioms or basic laws of a theory are guesses; they cannot be deduced or inductively inferred from experiences or observations.

Photo © Ullstein, Fed. Rep. of Germany

With his second wife Elsa, homeward bound after a trip to California. In the 1920s and early 1930s, Einstein travelled widely, visiting the United States, China, Japan and most of Western Europe to explain and discuss his theories.

On the other hand, a theory should permit the derivation of propositions which can be tested experimentally, and therein lies its value. Thus, science requires three human activities: free invention or guessing, logical-mathematical deduction, and observation or experiment.

As Einstein as well as Paul Dirac (see article page 17) remarked, the process of guessing is guided not only by factual experience and experience with previous theories, but also by a sense of structural simplicity and mathematical beauty. There is not much point in classifying Einstein as a positivist, a rationalist, an empiricist or any other "...ist", but if some such label were required, I would propose to call him a logico-empirical artist.

It appears that Einstein has strongly influenced natural philosophy not so much through his philosophical statements as such, but because of the manner in which he practised science, constructed new theories and thus contributed to knowledge, often in a surprising way.

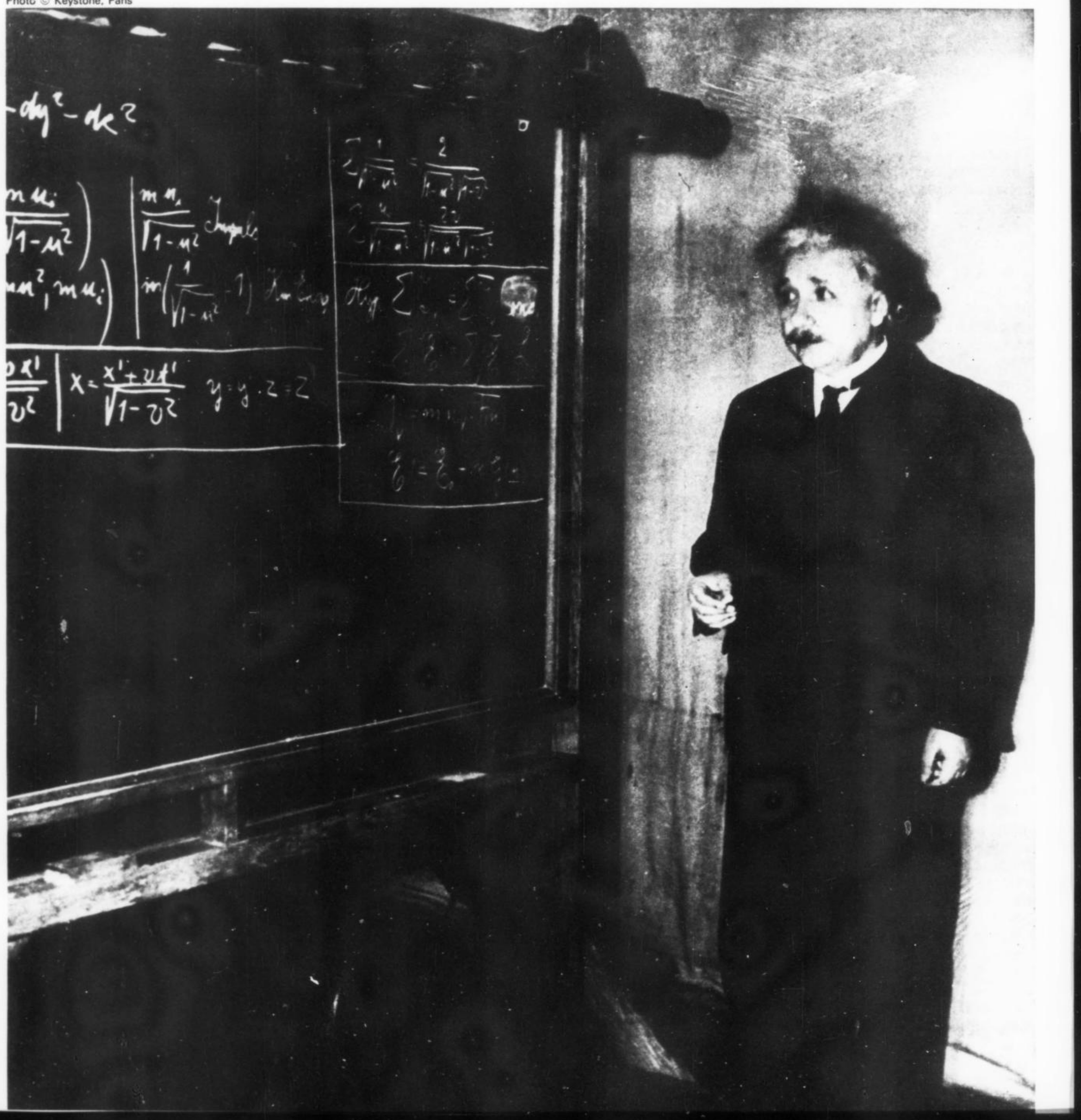
Einstein regarded himself as a physicist and not as a philosopher. He was proud of the general theory of relativity which he considered as his greatest intellectual achievement.

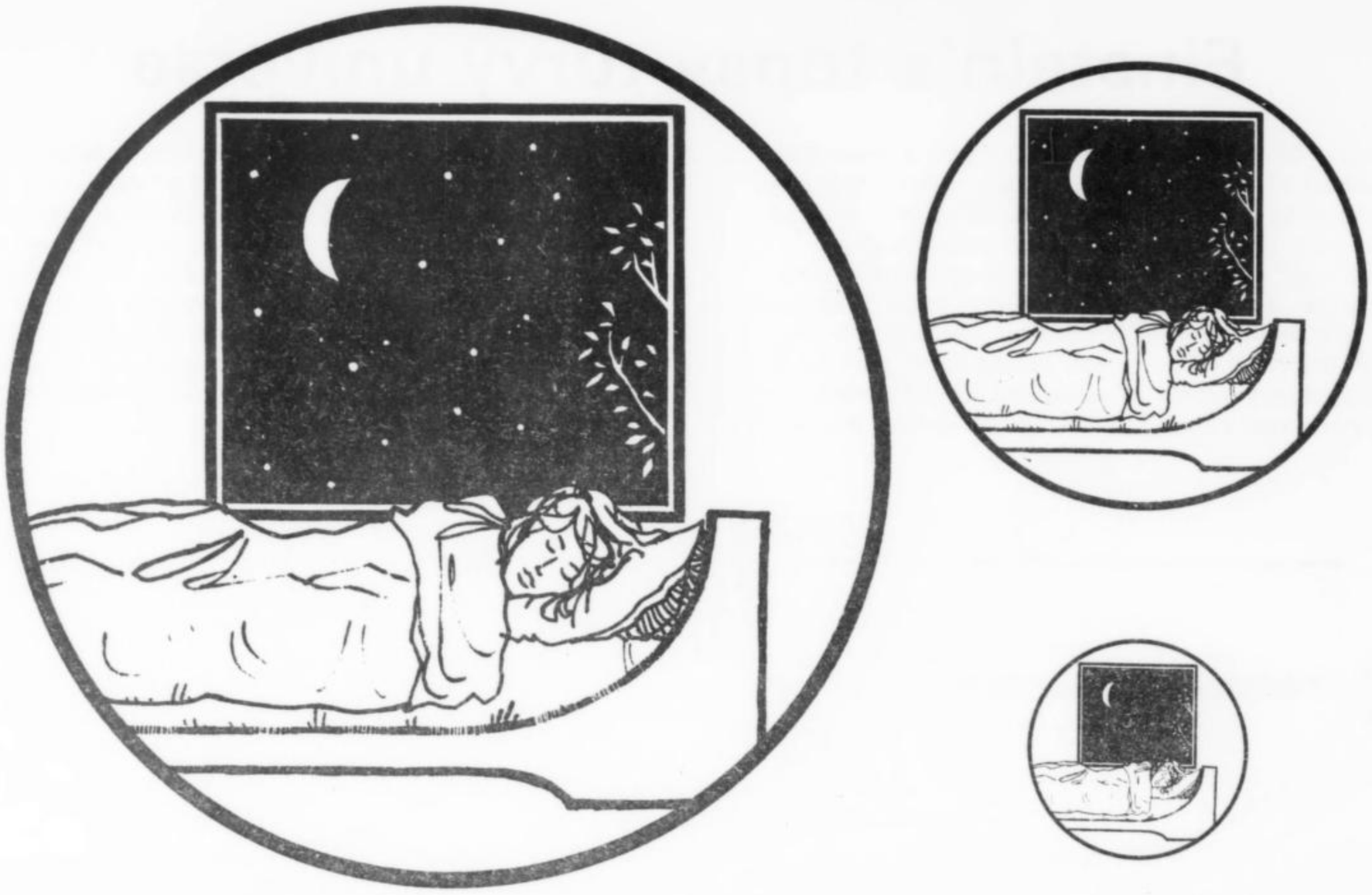
"Einstein's Theory of Relativity has advanced our ideas of the structure of the cosmos a step further", wrote the German mathematician Hermann Weyl. "It is as if a wall which separated us from Truth has collapsed. Wider expanses and greater depths are now exposed to the searching eye of knowledge, regions of which we had not even a presentiment. It has brought us much nearer to grasping the plan that underlies all physical happening."

■ **Jürgen Ehlers**

At the blackboard during a lecture to the American Association for the Advancement of Science. In 1933 Einstein accepted a post at the Institute for Advanced Study at Princeton, where he worked until he died in 1955, a page of uncompleted equations at his bedside.

Photo © Keystone, Paris





WHAT IS RELATIVITY ? The following way of illustrating the concept of relativity was thought up by the celebrated French mathematician Henri Poincaré. Just suppose, said Poincaré, that one night while you were fast asleep everything in the universe somehow became a thousand times bigger. *Everything :* the stars, the sun, the earth, your home, your bed, you yourself, the length of light waves, atoms and electrons. When you woke up, would you know that anything had changed ? No, said Poincaré; no experiment could possibly prove that anything had changed. It would be meaningless to say that the universe had become bigger, because if you say that a thing is "bigger" you imply that it is bigger than "something else" and in the case of the universe there is no "something else". In other words size is a relative concept.

Drawings Philippe Gentil Studio, Paris © *Unesco Courier*

Relativity in a nutshell

by Isaac Asimov

ACCORDING to the laws of motion first worked out in detail by Isaac Newton in the 1680s, different motions add together according to the rules of simple arithmetic. Suppose a train is moving away from you at twenty kilometres an hour and a person on the train throws a ball at twenty kilometres an hour in the direction of the train's motion. To the person, moving with the train, the ball is moving twenty kilometres an hour away from him. To you, however, the motion of the train and the ball add together, and the ball is moving away from you at the rate of forty kilometres an hour.

Thus, you see, you cannot speak of the ball's speed all by itself. What counts is its speed *relative* to a particular observer. Any theory of motion that attempts to explain the way velocities and related phenomena seem to vary from observer to observer would be a "theory of relativity".

Albert Einstein's particular theory of relativity arose from the fact that what works for thrown balls on trains doesn't seem to work for light. A moving source of light might cast a beam of light in the direction of its travel, or against the direction of its travel. In the former case, the light should (according to Newton's laws) travel at its own speed *plus* the speed of the light-source. In the latter case, it should travel at its own speed *minus* the speed of the light-source. That's the way the thrown ball on the moving train would behave.

Light doesn't behave so. It always seems to travel at its own speed regardless of the motion of the source. Einstein attempted to arrange the laws of the universe to account for that.

Einstein showed that, in order to account for the constancy of light's velocity, one had to accept a great many unexpected phenomena. He showed that ob-

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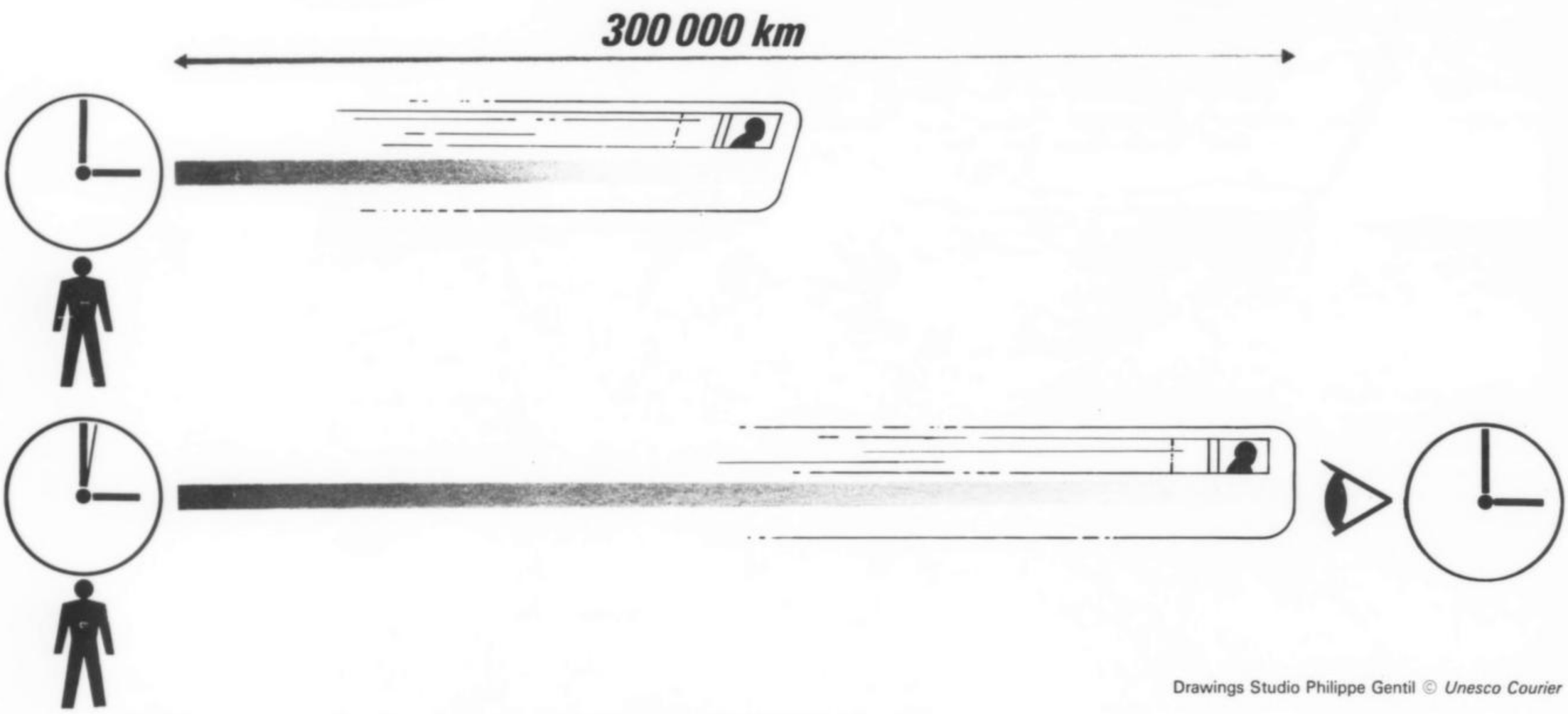
ISAAC ASIMOV *of the USA is internationally known as a popularizer of science and a science fiction writer. His huge output of published works reflects the variety of his interests which include : literary criticism, psychology, mathematics, mystery, poetry and humour. Earlier this year he published his 200th book, assigning the same number to two works:* Opus 200 *(Houghton Mifflin), an Asimov anthology, and* In Memory Yet Green *(Doubleday), the first volume of his autobiography.*

Einstein's topsy-turvy universe

The curious tale of a ride on a beam of light, clocks that run slower when they are in motion than when they are stationary, the long-playing record whose centre is older than its outer rim, light rays that bend, objects that change in size and weight, a man only half as old as his twin, black holes in space from which not even light can escape — all these Alice-in-Wonderland notions which seem to fly in the face of common sense form part of Einstein's topsy-turvy world of relativity. Did Einstein really throw common sense out of the window ? Not at all. The curious effects his theory postulates only become evident when we enter the world of very high velocities. Although they are of great importance in physics, in ordinary life they are so infinitesimal that they can be ignored. Many of the implications of the theory of relativity are so complex that they can only be fully expressed in mathematical terms. The drawings and captions on this and following pages are an attempt to give an approximate visual introduction to Einstein's mysterious universe.



Drawings Studio Philippe Gentil © *Unesco Courier*

A street-car named relativity

As a teenager in Zurich, Einstein asked himself a seemingly innocent question the answer to which contained the core of the principle of relativity. "What would the world look like", he pondered, "if I rode on a beam of light ?"

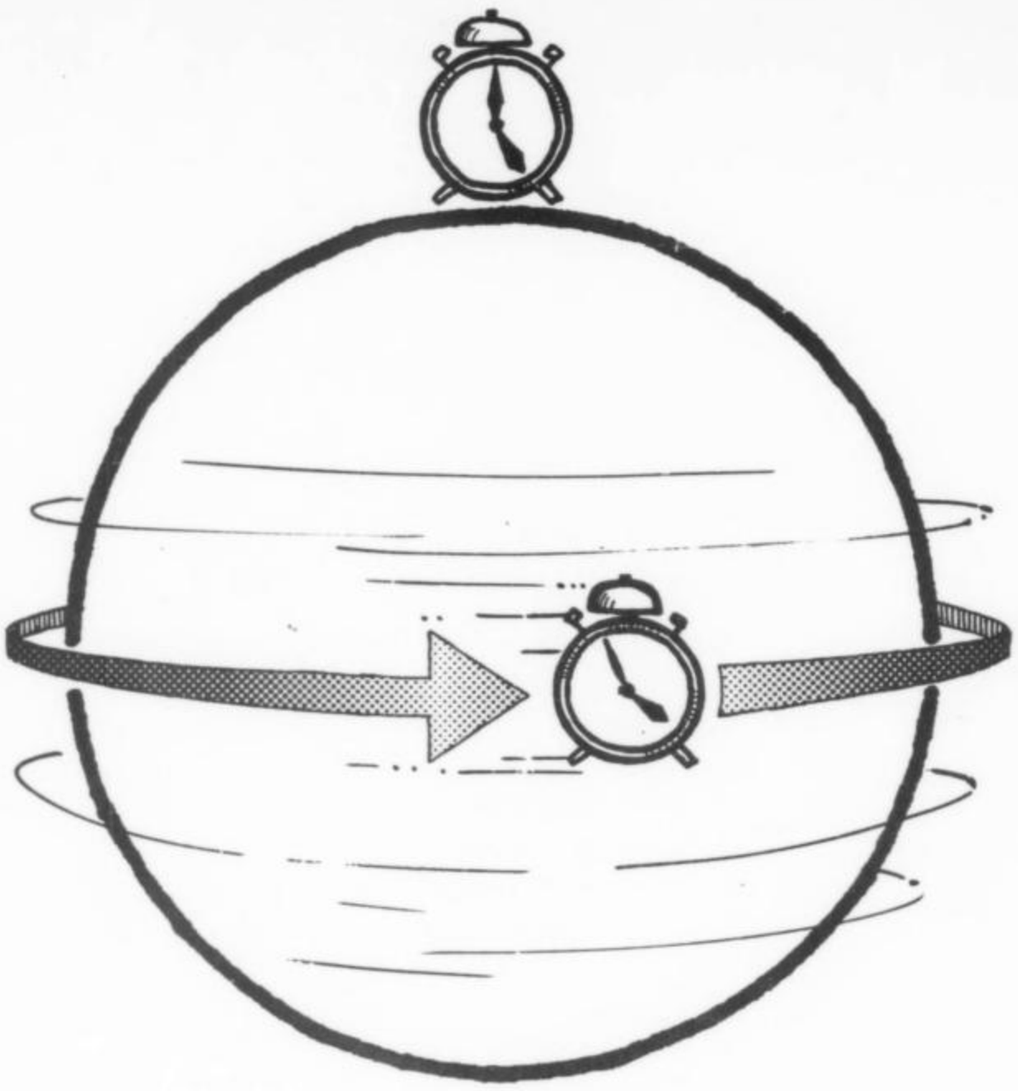
Let us make this imaginary journey with Einstein. Picture yourself boarding a street-car at the foot of a clock-tower in Berne, as Einstein used to do every day on his way to work at the Swiss Patent Office. Imagine that, instead of travelling along its usual track, the street-car carried you away at the speed of light (300,000 kilometres per second) on the very beam of light with which you saw the time indicated on the clock. Suppose the clock showed three o'clock when the street-car whisked you off to a destination 300,000 kilometres away. The journey ought to take you exactly one second. But the clock as you see it (assuming that you could see it from a distance of 300,000 kilometres) would still say three o'clock; this is because it takes the beam of light from the clock showing the time you set off as long as it has taken you to reach your destination. By keeping up with the speed of light you as a passenger in the street-car are cut off from the passage of time. But to a man left standing on the pavement in Berne the same clock would indicate one second past three. In other words, time runs differently for you in the street-car and for the man on the pavement in Berne; contrary to what Newton thought, therefore, there is no such thing as universal time. Furthermore, although in the street-car you discover the same laws, the same relations between time, distance, speed, mass and force as everyone everywhere discovers, the actual *values* that you get for time, distance, and so one, are not the same as for anyone else. The only value that is invariably the same for everyone is the value for the speed of light.

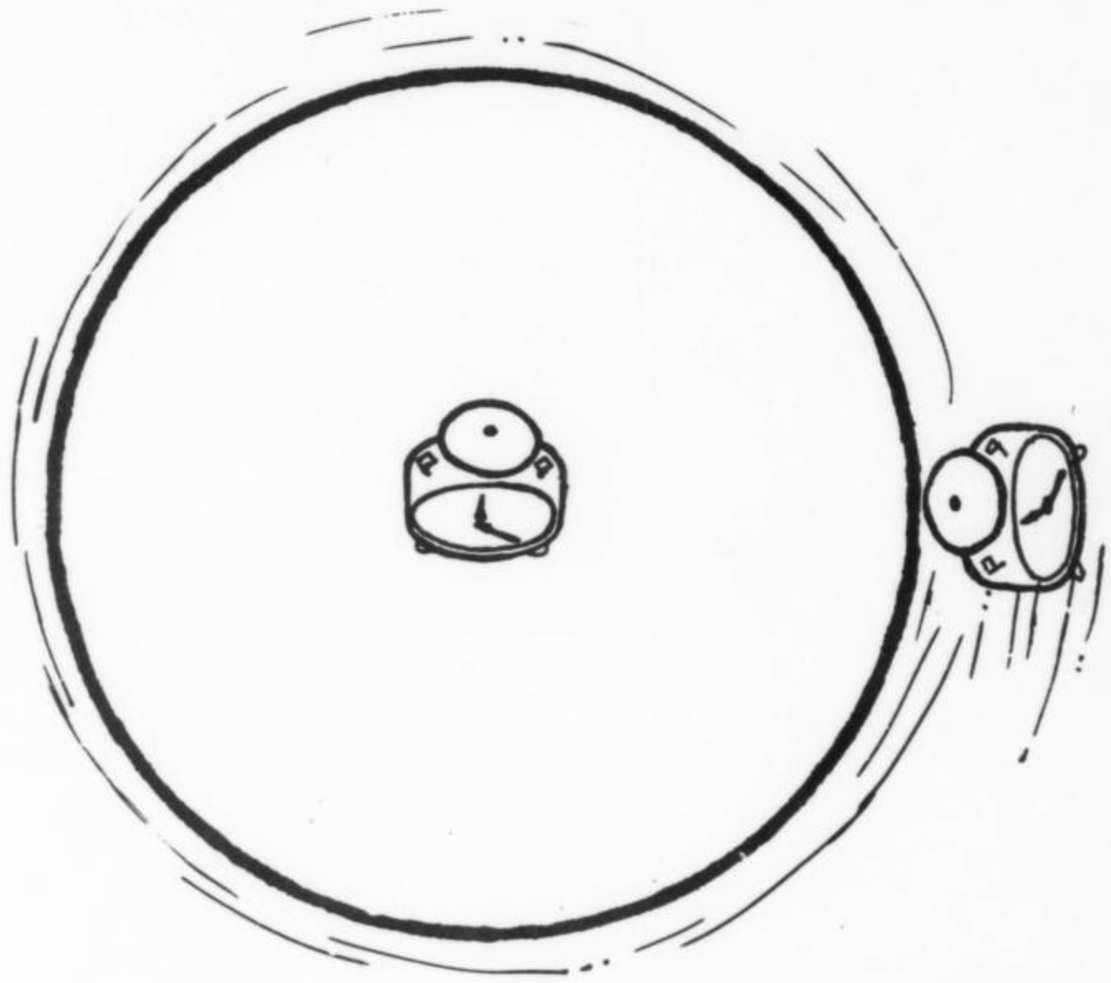
For Newton, time and space formed an absolute framework and the world looked the same to every observer, wherever he might be and however he might travel. For Einstein, what two observers see is relative to each of them, to their position and their speed. We cannot know what the world is like, we can only compare what it looks like to each of us. Relativity is the understanding of the world not as events but as relations.

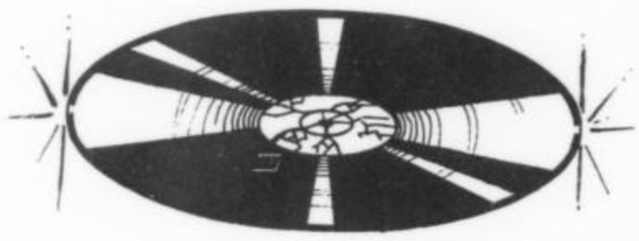
jects would have to grow shorter in the direction of their motion—shorter and shorter as their motion was faster and faster, until they would have zero length at the speed of light; that moving objects would have more and more mass the faster they moved till their mass was infinite at the speed of light; that the rate at which time progressed on moving bodies decreased the faster they moved till it stopped altogether at the speed of light. For each of these reasons the speed of light in a vacuum was the maximum speed that could be measured.

Furthermore, he showed that a little bit of mass was equal to a great deal of energy, according to his famous equation, $E = mc^2$, where c stands for the speed of light.

All this, he worked out in 1905 for bodies moving at the same speed in an unchanging direction. This special kind of motion







Time out of joint

A curious prediction of the theory of relativity was that a stationary clock would run faster than a moving clock. In 1905, Einstein wrote "that a clock fixed at the earth's equator will run slower by a very small amount than an identical clock fixed at one of the earth's poles". This was proved experimentally by the English scientist H.J. Hay who visualized the globe squashed into a flat disc with the North Pole at the centre and the equator at the rim. Placing a radio-active clock at the centre and another at the rim he set his model turning. Einstein's prediction was proved correct, the clock at the rim kept time more slowly than the clock at the centre. This holds true for any spinning disc on every turntable, and each time a long-playing record revolves on a record-player its centre is ageing faster than its rim.

was dealt with in Einstein's "special theory of relativity."

The effects predicted by Einstein are noticeable only at great speeds. The simple arithmetic of Newton's laws therefore works at ordinary speeds, simply because Einstein's effects are too small to notice. Because we are always surrounded by the working of those laws, they come to seem like "common sense" to us while Einstein's effects seem strange.

Nevertheless, at the time Einstein published his theory, scientists were working with subatomic particles hurled outward by exploding atoms. These subatomic particles moved at great speeds and the Einstein effects could be noted in them exactly. Atom-smashing machines and nuclear bombs couldn't exist unless the special theory of relativity was correct.

In 1916, Einstein worked out a more complicated version of the theory of relativity, one that included not only motion at constant speed in the same direction—but any kind of motion at all, motion that changed speed or direction or both. Since it dealt with any motion in general, this version of his theory is "the general theory of relativity."

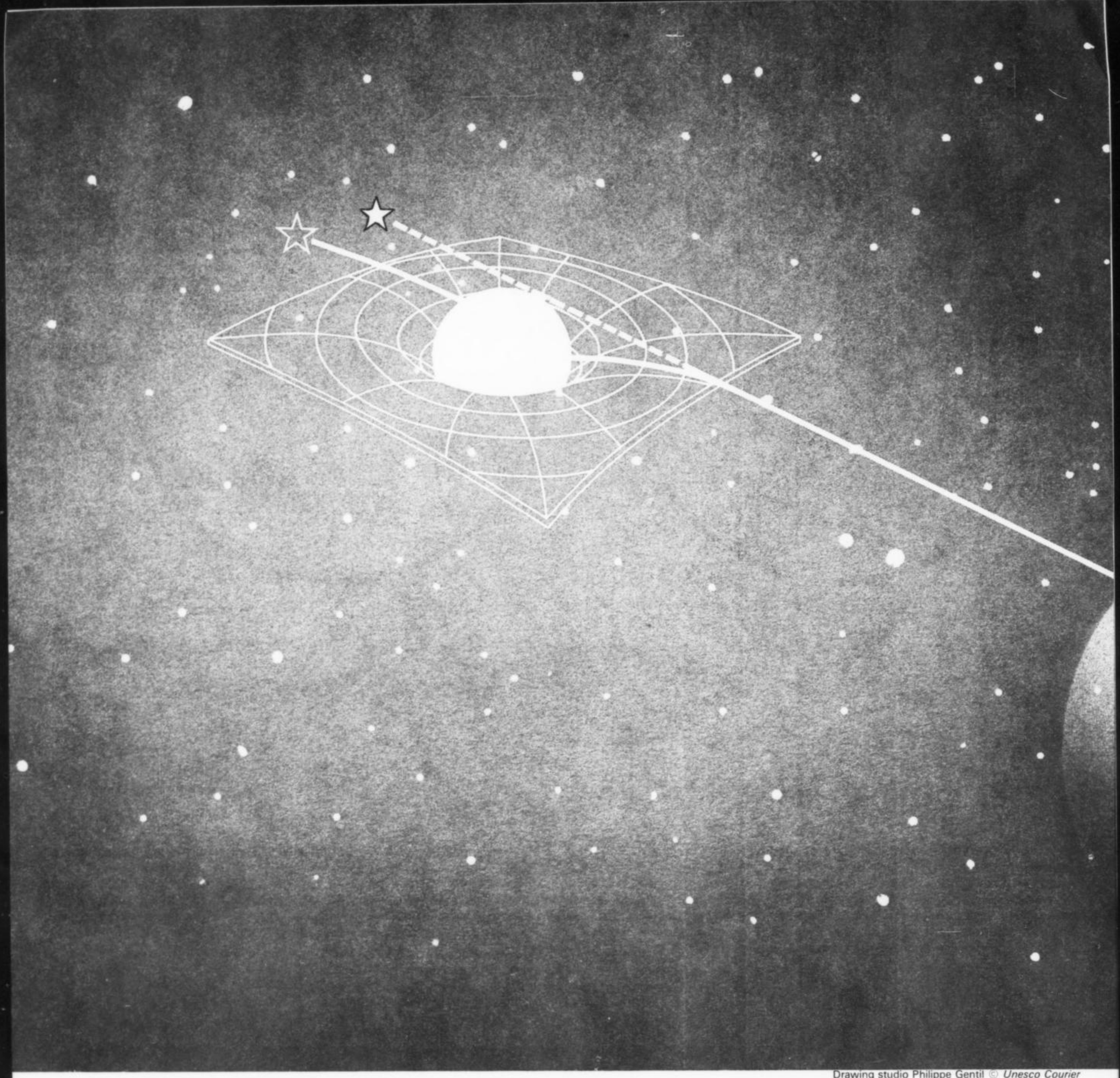
The most common reason why objects move at varying speeds and in changing direction is because a gravitational force is acting on them. A ball when dropped moves faster and faster because earth's gravity is pulling it. A thrown ball follows a curved path because earth's gravity is pulling it. The earth follows a curved path in space because the sun's gravity is pulling it.

For this reason, Einstein's general theory had to deal with gravitation.

Einstein worked out a set of equations which showed that if there were no matter anywhere and no gravitation, a moving body would follow a straight line. If there were matter, the surrounding space would be distorted so that the moving body would follow a curved line. Einstein's general theory showed what those curves ought to be and they weren't quite what Newton's theory of gravitation predicted.

The differences between Einstein's equations and Newton's equations are very slight indeed, and only the most careful and delicate measurements can show us which set of equations is actually followed by moving bodies.

One way of telling whether Einstein or Newton is right is by studying the behaviour of light when it passes through a strong gravitational field. According to Einstein, the light would pass through the distorted space and follow a very slightly curved path. This would not be so according to the Newtonian rules.



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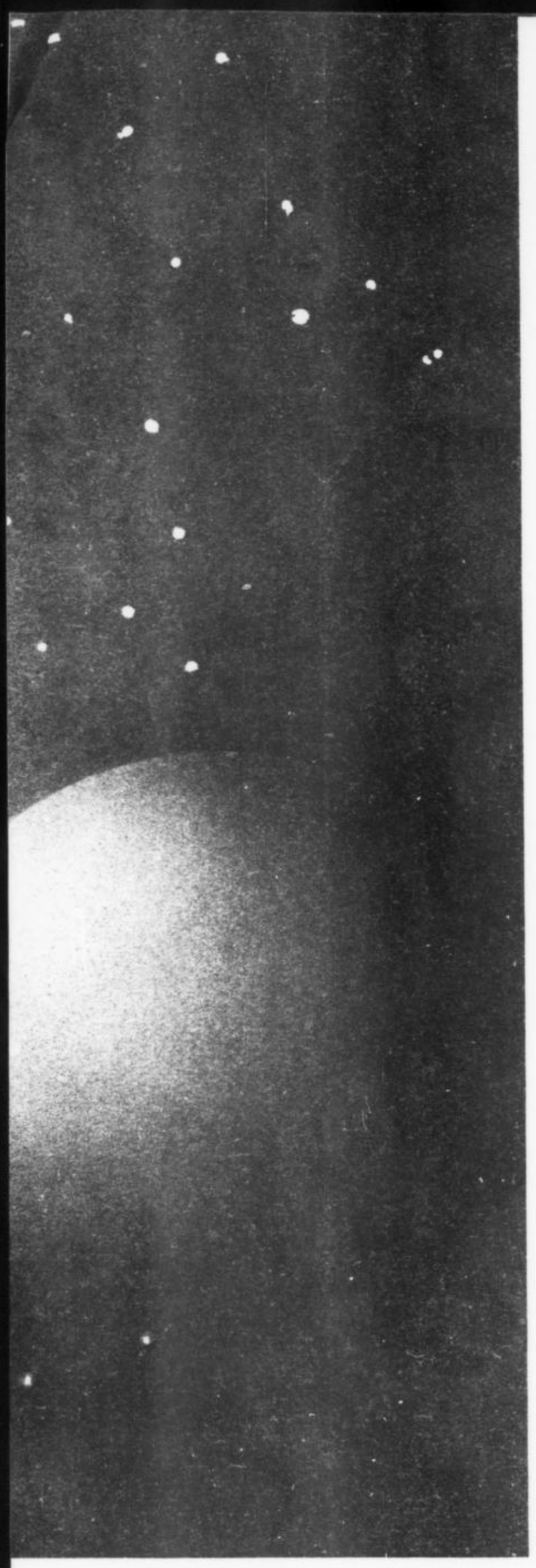
A matter of gravity

To Newton, gravitation represented the mutual attraction of masses of matter, the power of bodies to influence each other in proportion to their size and the distance between them. This force acted everywhere in the cosmos, whether causing an apple to fall to the ground or the moon to circle the earth. Setting aside this concept of an active force, which formed the underlying mechanism of the Newtonian universe, Einstein thought in terms of the "gravitational field". Thus the gravitational field of the earth governed the fall of Newton's apple and the solar gravitational field governs the motion of the planets around the sun. Matter, Einstein maintained, creates this gravitational field by distorting what he called the "space-time continuum" around it. This has been likened to an outstretched rubber sheet which is deformed by heavy objects (the sun, the stars) placed upon it. Diagram shows how light rays move along the curves thus formed and are thus "bent" round large heavenly bodies. Einstein predicted that starlight passing near the sun would follow the curved pathways in space caused by the sun's presence, thus seemingly "bending" round it. His prediction was confirmed in a famous experiment by the English astronomer Sir Arthur Eddington in 1919 (see page 19)



In 1919, a total eclipse was observed and the positions of the stars near the sun were accurately measured. If the light travelled a curved path, each star should seem to be a little farther from the sun than it ought to be. The amount of displacement would depend on how near the sun the light passed. Einstein's theory predicted exactly how large the displacement ought to be. The measurements at that 1919 eclipse, and at every total eclipse since then, seem to place the stars where Einstein predicted they would be.

These were hard measurements to make, though, and difficult to get exact. In our space age, we have been able to do better.

In 1969, for instance, two probes were sent toward Mars. When the probes were on the other side of the sun, the radio waves that they beamed back to earth had to pass near the sun and therefore followed a distorted path. Because of the distortion, the path was longer than a straight line would have been, and it took a bit more time for the waves to reach us. It took them a ten-thousandth of a second longer, actually, something which could be measured and which was just what general relativity predicted.

Another prediction of Einstein's general theory is that in space distorted by gravity time slows up.

A large object giving off light, emits that light in waves that are longer than they would be otherwise, because the slowing of time in the object's gravitational field keeps one wave going longer before the next one comes out. Even the sun, though, has a gravitational field that is not strong enough to show a measurable effect.

Just about the time Einstein advanced his theory of general relativity, however, a new kind of star was discovered. This was the "white dwarf." A white dwarf might have all the mass of the sun squeezed down into a volume no larger than that of the earth. Its gravitational field at its surface would be two hundred thousand times as intense as the sun's gravitational field was.

Particular light-waves emitted by a white dwarf would have to be longer by a particular amount than those same light-waves emitted by the sun. In 1925, measurements were taken of the light coming from a white dwarf and were found to be longer by just the right amount predicted by Einstein.

It was, of course, very difficult to take the measurement of the light from a white dwarf. Such stars are very dim and trying to analyse their feeble beams of light is a tricky matter.

It has been found, however, that under certain conditions, a collection of atoms in a crystal would emit gamma rays. Gamma rays are made up of waves like those of light, but much shorter. The crystal emitted gamma rays that all had the same wavelength exactly, and the wavelength could be measured with great accuracy.

If Einstein's general theory were correct, however, the gamma ray wavelength could be slightly changed if the gravitational pull upon the crystal were either increased or decreased.

Here on earth, gravitation increases as one gets closer to earth's centre. If you live in an apartment house, earth's gravity gets stronger with each floor you descend—but so slightly that you can't possibly tell the difference.

But it shows up in the gamma rays. As the crystal was taken down from the attic to the basement, the wave grew very slightly (but detectably) longer, and by ex-

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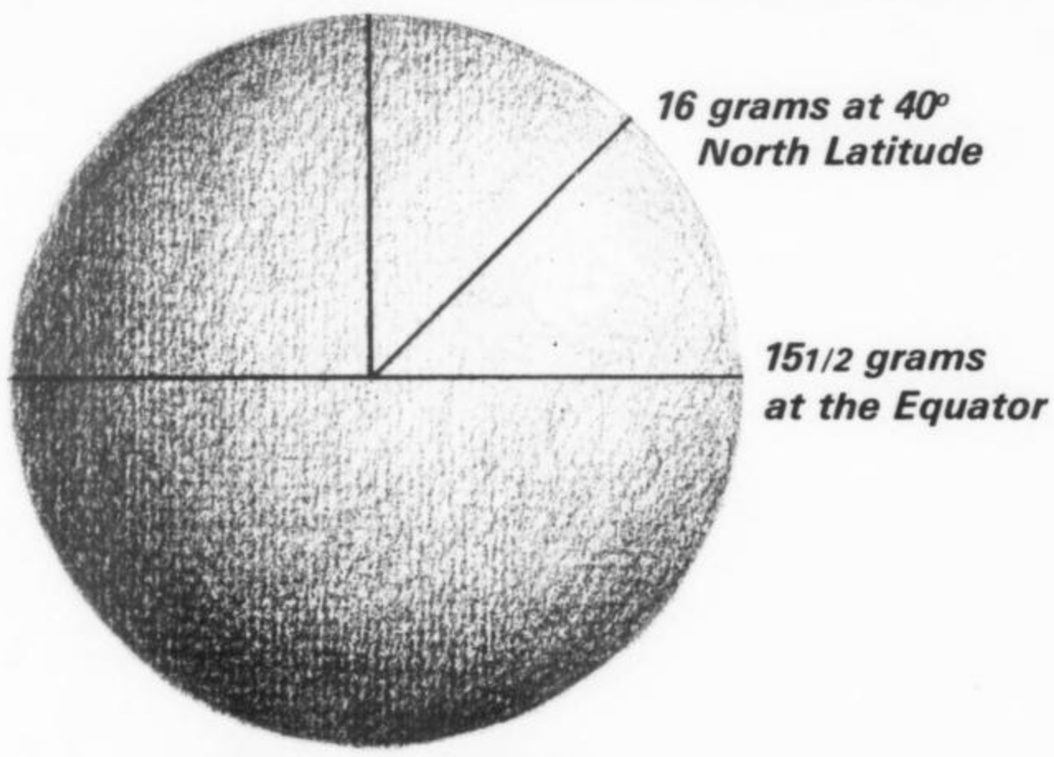

An object does not weigh the same at all points on the earth's surface. This is because the earth is not perfectly round and it is rotating. An object would weigh nothing at the centre of the earth because the earth's matter pulls on it equally from all directions.

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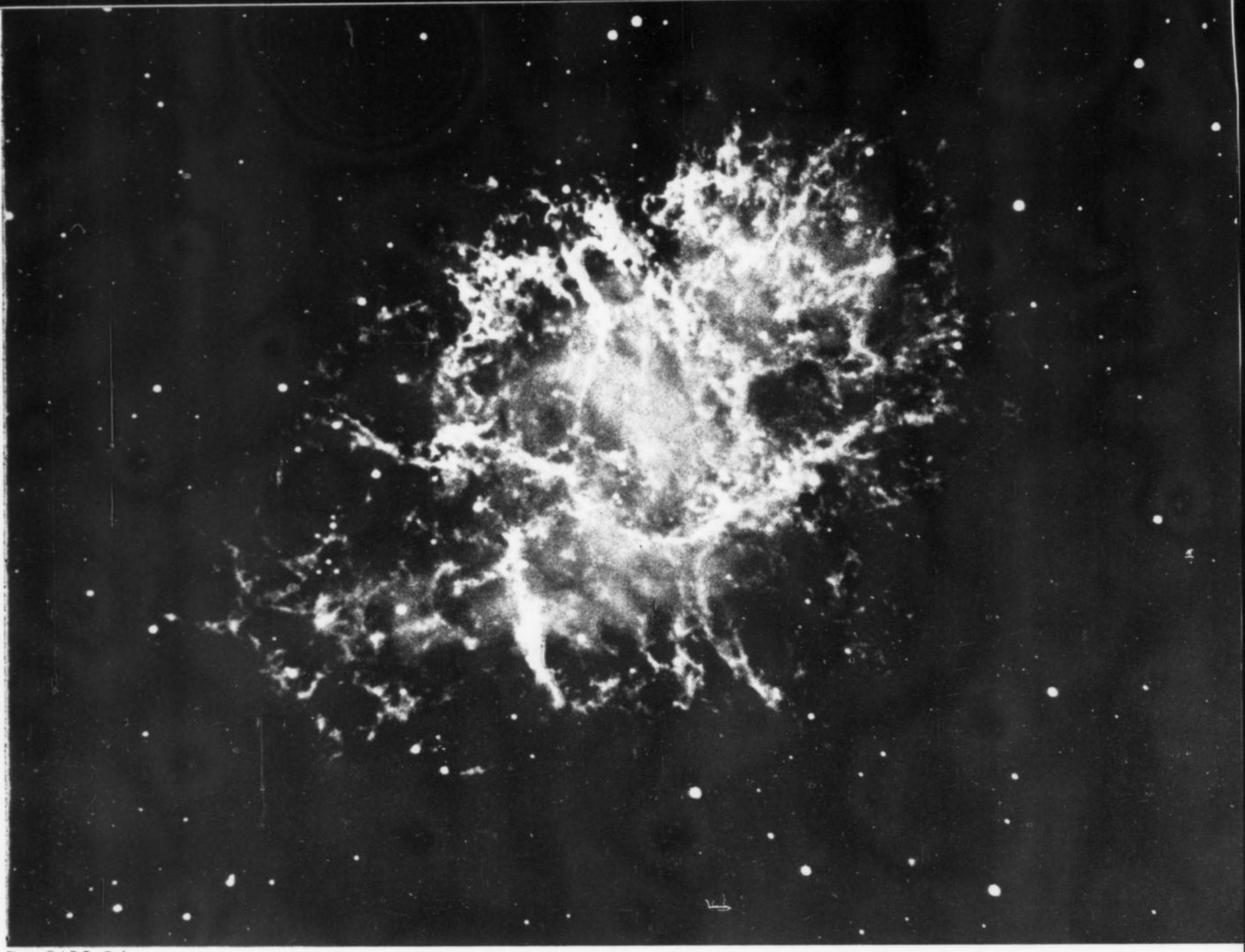
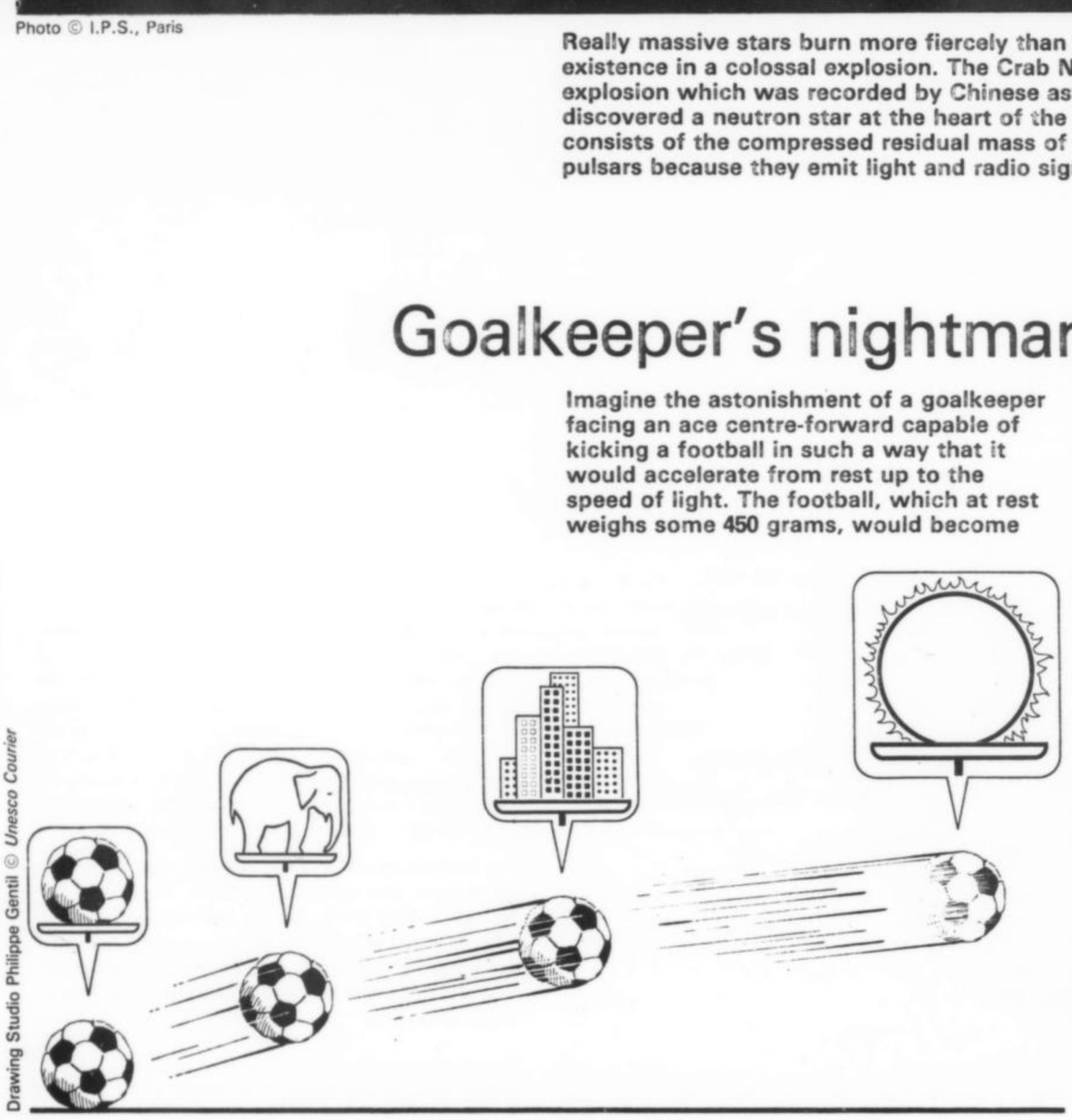


Photo © I.P.S., Paris

Really massive stars burn more fiercely than the sun, have much shorter lives and end their existence in a colossal explosion. The Crab Nebula, above, consists of the remains of a star explosion which was recorded by Chinese astronomers in AD 1054. In 1969, astronomers discovered a neutron star at the heart of the nebula. This small but extremely dense body consists of the compressed residual mass of the original star. Such bodies are also known as pulsars because they emit light and radio signals in regular pulses.

Goalkeeper's nightmare

Imagine the astonishment of a goalkeeper facing an ace centre-forward capable of kicking a football in such a way that it would accelerate from rest up to the speed of light. The football, which at rest weighs some 450 grams, would become heavier and heavier, becoming heavier than an elephant, a group of buildings and even the sun until finally, at the speed of light, its weight would become infinite. All this can be deduced from Einstein's famous equation $E = mc^2$ (energy equals mass multiplied by the velocity of light squared). The equation tells us that if we divide the energy of motion (kinetic energy) of the football by the square of the velocity of light, we will discover the football's mass; since its energy is increasing with acceleration, then its mass must also be increasing. Mass has been defined as the amount of matter of which an object consists, but scientists prefer to define mass as a measure of inertia, the resistance of all matter to being accelerated. In everyday life we usually measure weight rather than mass; indeed the two are very closely related, although weight is a more complicated notion than mass because it depends upon the strength of the earth's gravitational field.



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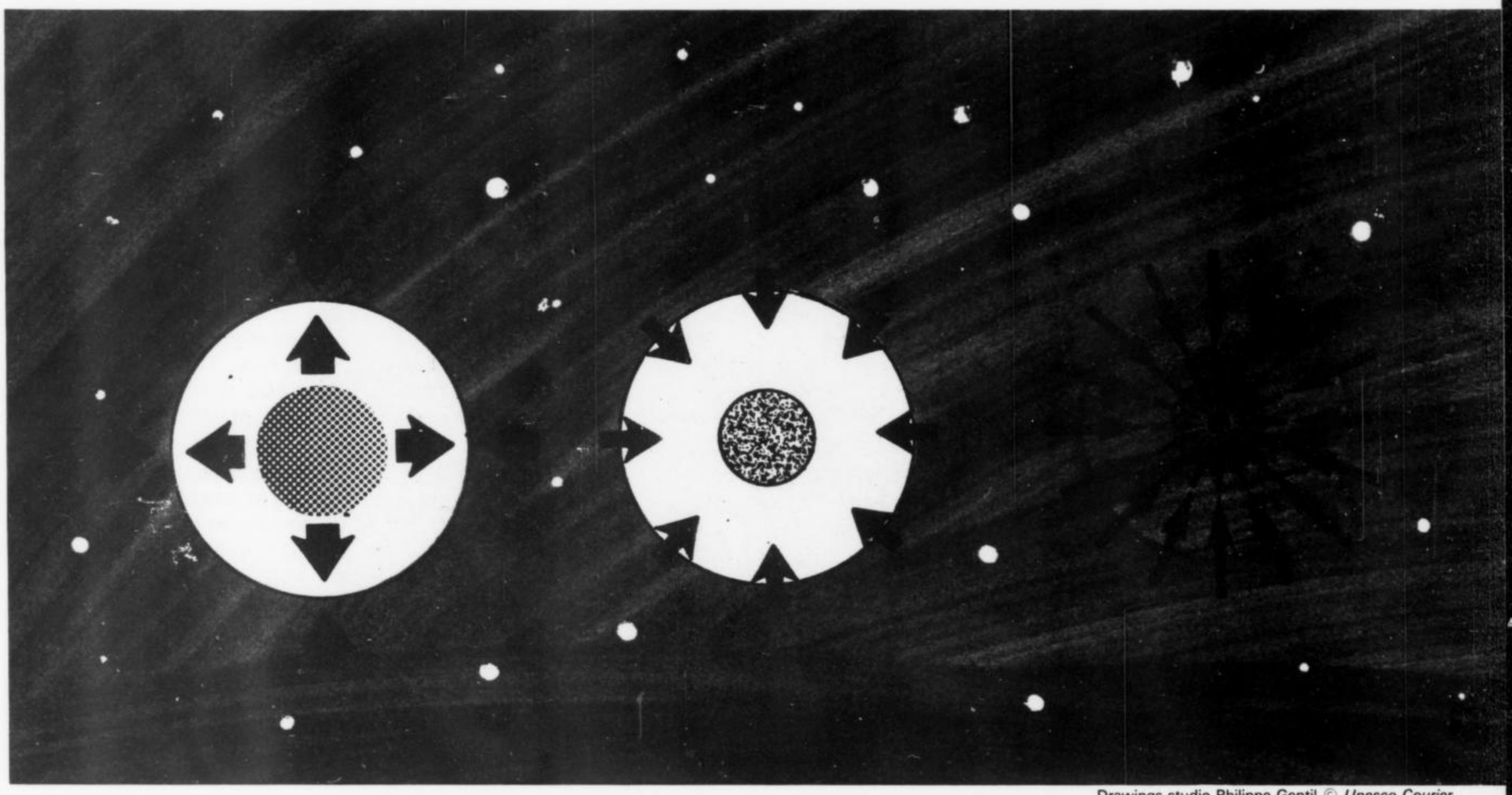

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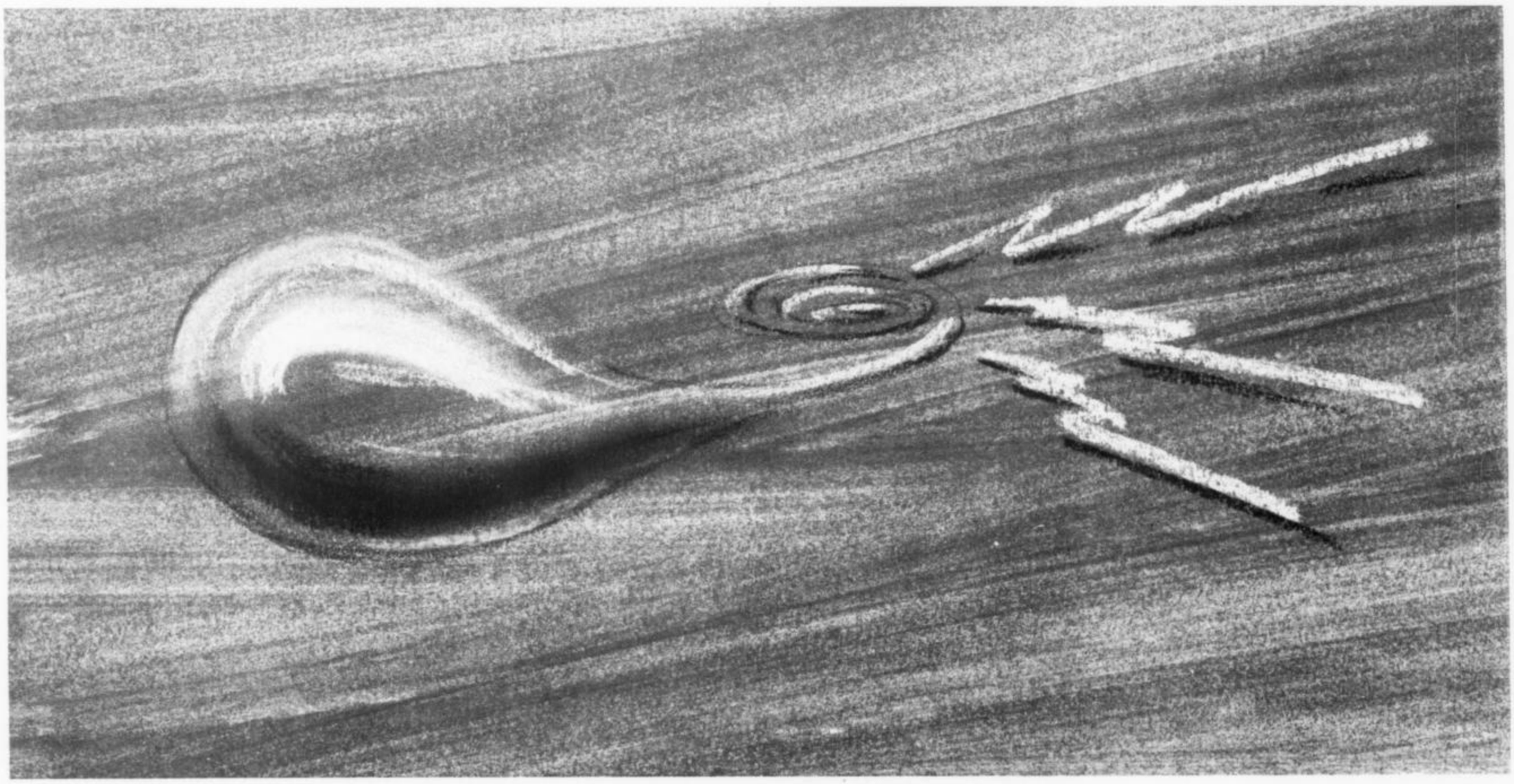
Giant stars and black holes

When we look up into the sky at night, we can see stars because they emit light. But one of the most baffling consequences of Einstein's general theory of relativity is the possibility of the existence of "black holes", the "corpses" of what were once massive stars, which we cannot see because their gravitational field is so intense that not even light can escape from them. How are black holes formed ? And if we cannot see them how do we know that they exist ? The diagrams above illustrate, from left to right, the stages in the formation of a black hole. During the stable life of a massive star equilibrium exists between gravitational pressure (represented by the inward-pointing arrows) and radiation and the heat from the star's core (outward-pointing arrows). But as the star burns up its core of nuclear fuel the equilibrium is broken and the star begins to collapse towards its centre (middle diagram). Finally, the star crushes itself into a tiny volume of enormous gravity and density. Black holes, by definition, can never be visible even to the most powerful telescope, but their presence can be detected by their effect on neighbouring visible stars. With their immense gravitational pull, black holes act like vast vacuum cleaners in space sucking in everything they meet. Below, gases from a visible massive star (left) are pulled towards the invisible black hole. As these gases spiral into the black hole they are heated and compressed and emit X-Rays that astronomers can detect.



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actly the amount predicted by Einstein's theory.

Still another consequence of Einstein's treatment of gravitation in his general theory of relativity is that gravitation, like light, can be given off in waves. In this way, gravitation, like light, can carry energy away from the object giving it off.

Such gravitational waves are given off when an object moves round and round in response to gravitation, or back and forth, or pulses in and out. The earth, when it moves around the sun, gives off gravitational waves, according to Einstein. It is losing energy so that it is slowly dropping in closer to the sun.

Gravitational waves are so weak, however, and carry so little energy that the waves given off by earth are far too feeble to be detected. The energy they carry off is so tiny that earth won't drop closer to the sun by more than a few metres in billions of years.

It may be, though, that somewhere in the universe there are more intense gravitational fields than there are here in the solar system. Extremely rapid motions may involve the giving off of gravitational waves that are just barely energetic enough to detect.

Many scientists have been trying to detect such gravitational waves using very delicate instruments. Some have reported success, but the results were very borderline and such reports have not yet been accepted.

In 1967, however, a new kind of star was discovered, a "pulsar". Such a star is even smaller and more compressed than a white dwarf is. A pulsar may have a mass equal to our sun and yet have it all squeezed into a little ball no more than twelve kilometres across. The gravitational field at the surface of such a pulsar would be 10,000,000,000 times that of the sun.

In 1974, two pulsars were found that circled each other. With circlings in so incredibly powerful a gravitational field, effects that are barely noticeable in our solar system become easy to measure.

For instance, there is a small component of Mercury's motion about the sun that isn't accounted for by Newton's theory of gravitation. A particular point in Mercury's orbit makes a complete circle about the sun in a little over 3,000,000 years although by Newton's theory it shouldn't move at all. Einstein's theory, however, accounts for the motion exactly.

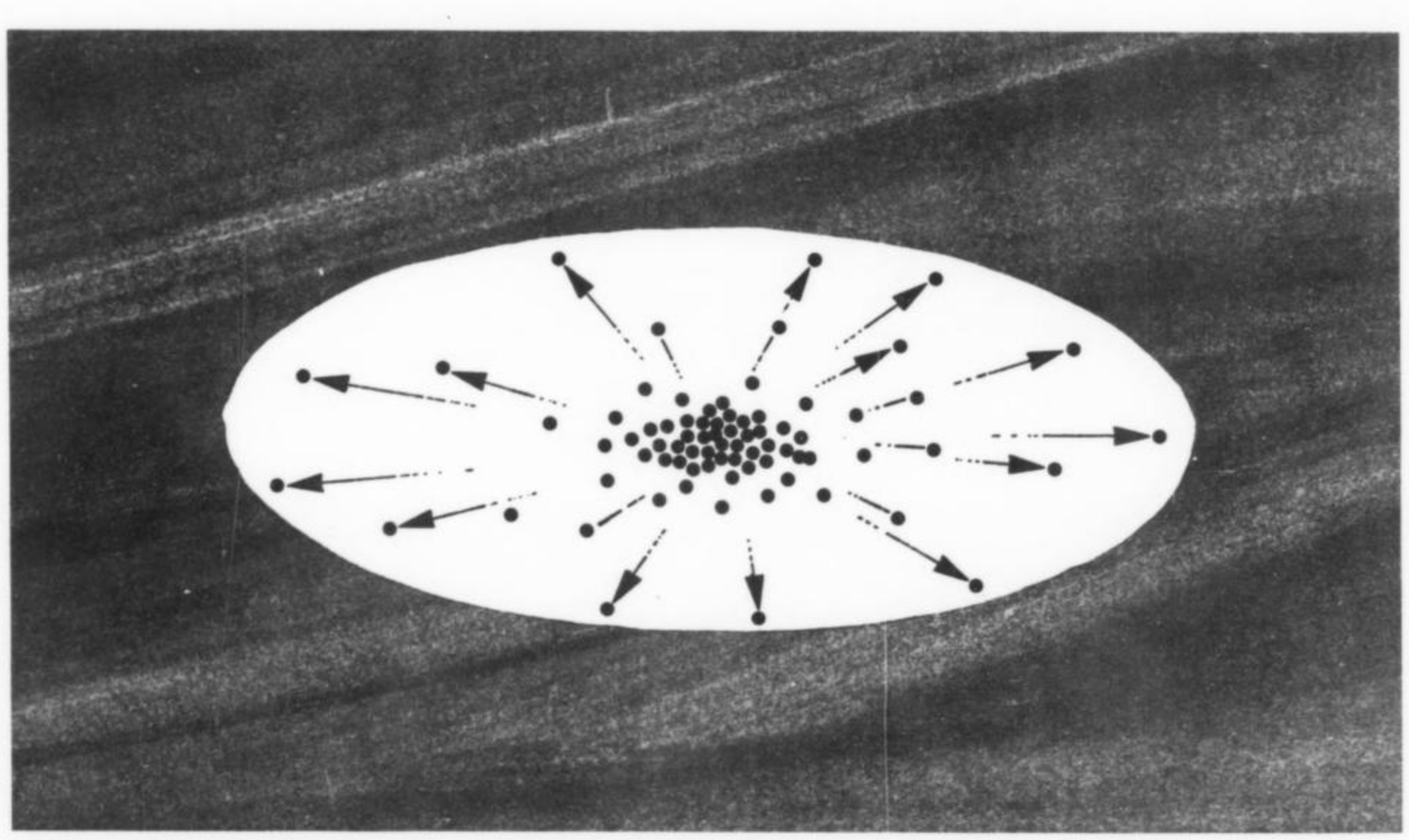
That same point in the orbits of that pair of circling pulsars should make a complete circle in a mere eighty-four years according to Einstein's theory, and the point is moving at the proper speed to do so.

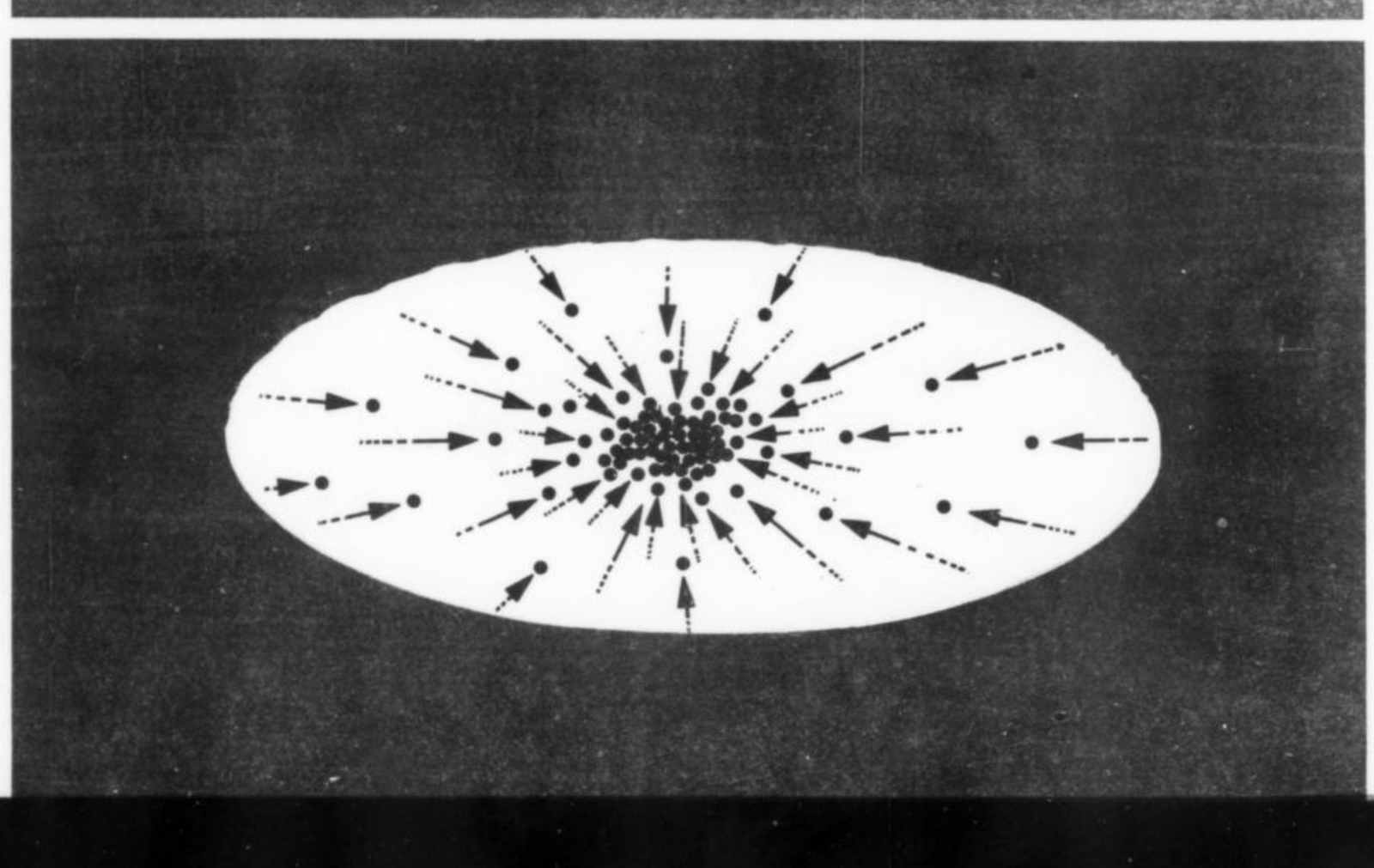
What's more, the pulsars should be giving off gravitational waves as they revolve, much stronger ones than earth does. The energy carried off by the gravitational waves ought to be enough to cause the pulsars to be spiralling in toward each other at a noticeable rate. This, in turn, should cause certain radio wave pulses they give off to reach us at shorter and shorter intervals.

In 1978, delicate measurements of those radio pulses were made and they were found to be coming at shorter and shorter intervals by just the predicted amounts.

What it comes to is this: In the three-quarters of a century since Einstein advanced his theory of relativity, scientists have tested it in every way they could think of, over and over again, and Einstein's theory has passed every single test they have devised without exception.

■ **Isaac Asimov**





Einstein's work gave new impetus to cosmology, the study of the universe as a unified whole. The Russian mathematician Alexander Friedmann had shown that Einstein's theories suggested that the universe was unstable and probably expanding. Einstein himself was at first unable to accept the logic of his own equations and in order to arrive at a closed model of the universe he introduced a factor into his gravitational equations which he called the "cosmological constant" (see article page 29). In 1924, the American astronomer Edwin Hubble proved experimentally that Friedmann's view was correct, that the distant galaxies were receding at increasing speeds and that the universe was in fact expanding. Einstein finally bowed to the evidence and described his earlier stance as "the biggest blunder of my life". Right, representations, top, of an open universe which will expand for ever, and, bottom, of a closed universe that will eventually contract.

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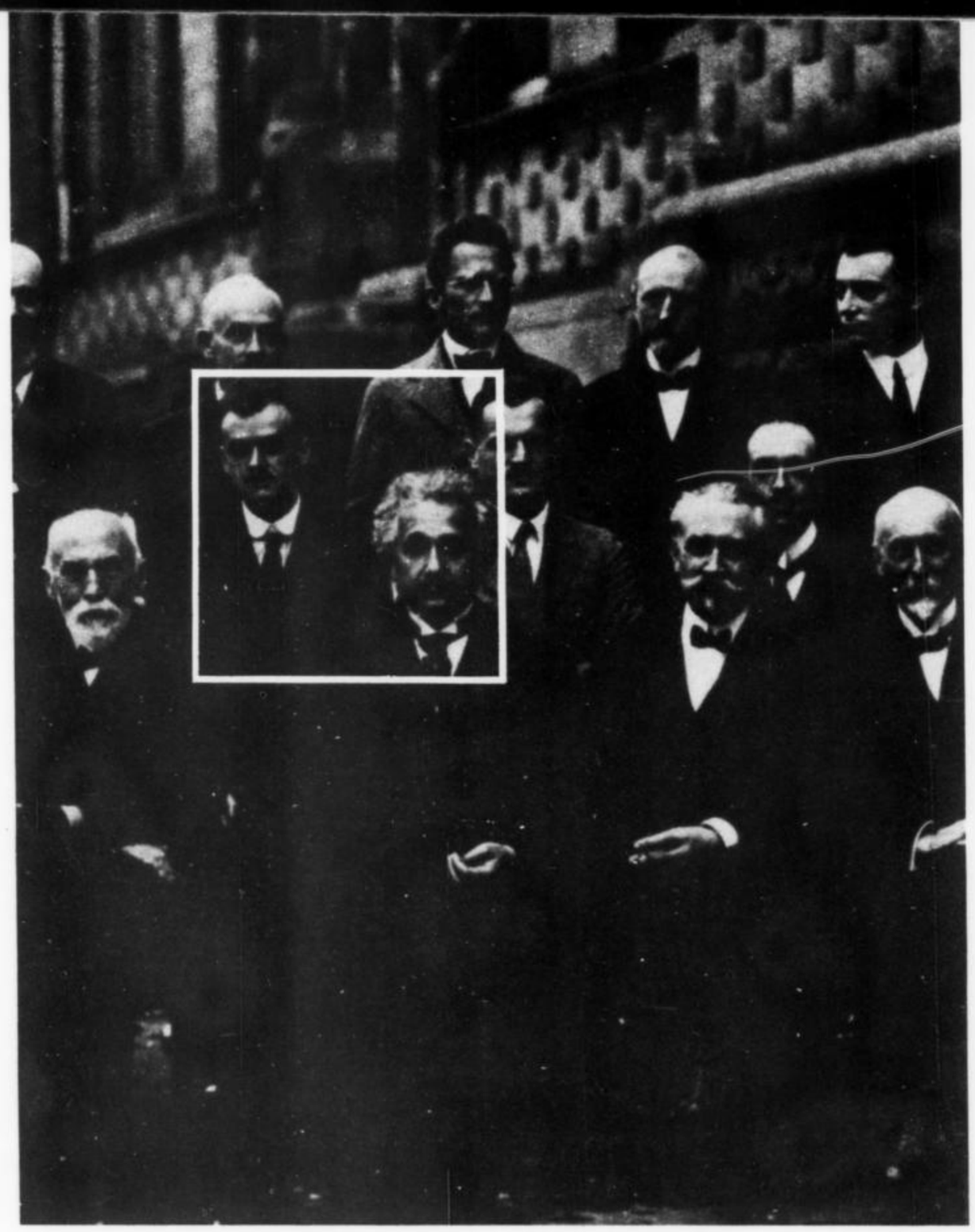

Paul Dirac seen with Einstein at the fifth Solvay Conference, held in Brussels in October 1927.

Photo © Palais de la Découverte, Paris

The test of time

by Paul Dirac

THE big discoveries in science are made in two ways. Sometimes the time is ripe for a certain discovery and there are many people hot on the trail. It becomes a race between them and whoever wins the race gets the credit.

If you look through the list of Nobel Prize winners you will see that very often the prizes are awarded to two or three people who have worked on the same subject and the credit is divided between those who win the race. This kind of discovery is such that if one particular man had never existed the discovery would soon have been made by somebody else.

Now there is another kind of scientific discovery where one man works all alone, follows new lines of thought entirely by himself with no rivals and no competitors. He goes into new domains of thought which no one has previously entered. The work of Einstein is mostly of this kind.

If Einstein had not existed these discoveries would not have been made by anybody else for many years or for many decades. Einstein alone entirely changed the course of scientific history.

Einstein's theory of relativity remained unknown, except to a few specialists, until the end of 1918, when the First World War came to an end. It then came in with a terrific impact. It presented the world with a new style of thinking, a new philosophy.

It came at a time when everyone was sick of the war, those who had won as well as those who had lost. People wanted something new. Relativity provided just what was wanted and was seized upon by the general public and became the central topic of conversation. It allowed people to forget for a time the horrors of the war they had come through.

Innumerable articles about relativity were written in newspapers and magazines. Never before or since has a specific idea aroused so much and such widespread interest. Most of what was said and written referred to general philosophical ideas and

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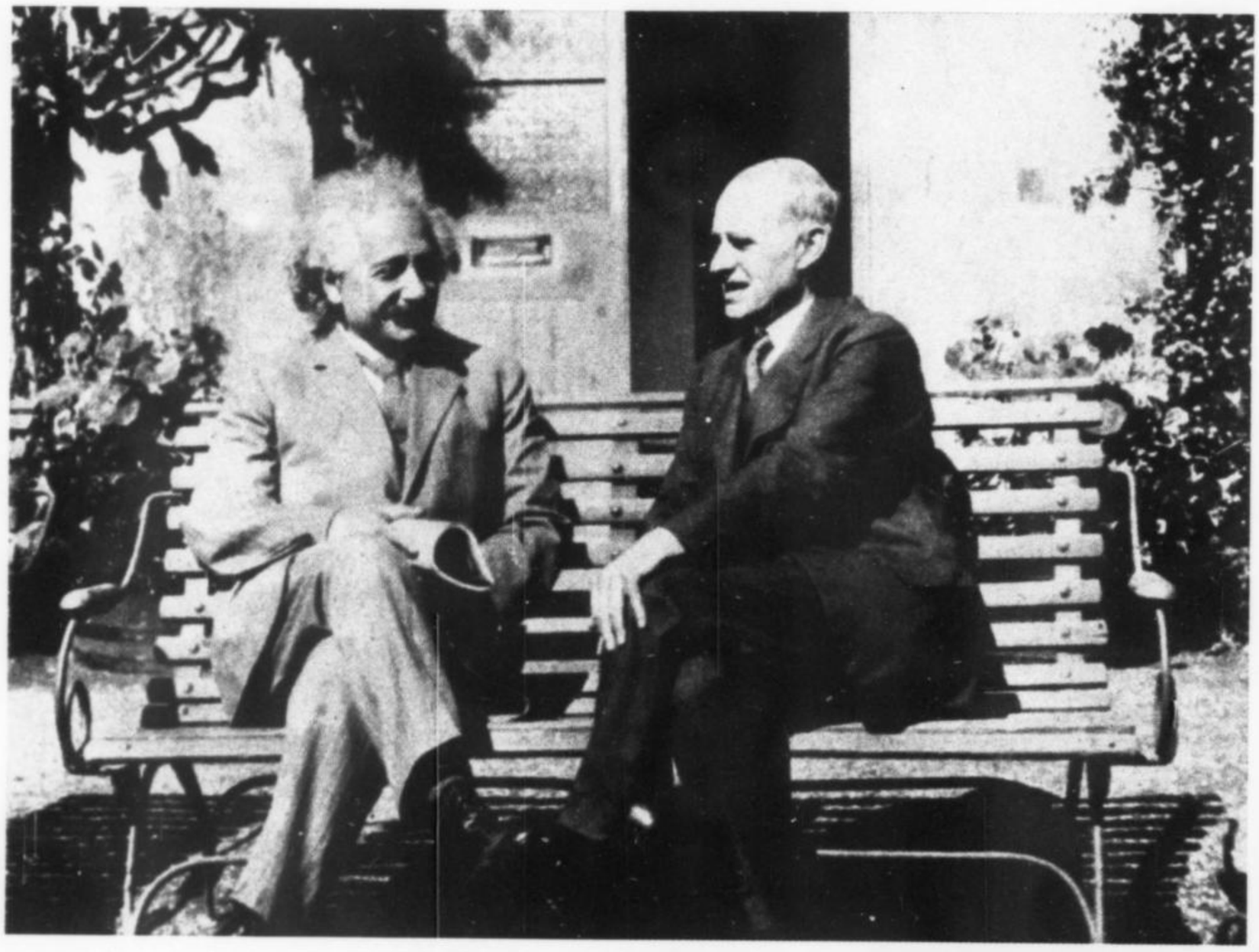
PAUL DIRAC, *eminent British physicist, won the 1933 Nobel Prize in physics with Erwin Schrödinger, an Austrian scientist, for his brilliant studies and research in atomic physics. He is a Professor Emeritus of Cambridge University and Professor of physics at Florida State University, USA. This article is an abridged version of a lecture given by Prof. Dirac at a Unesco symposium on the Impact of Modern Scientific Ideas on Society, held in September 1978 at the Universities of Munich and Ulm (Federal Republic of Germany).*



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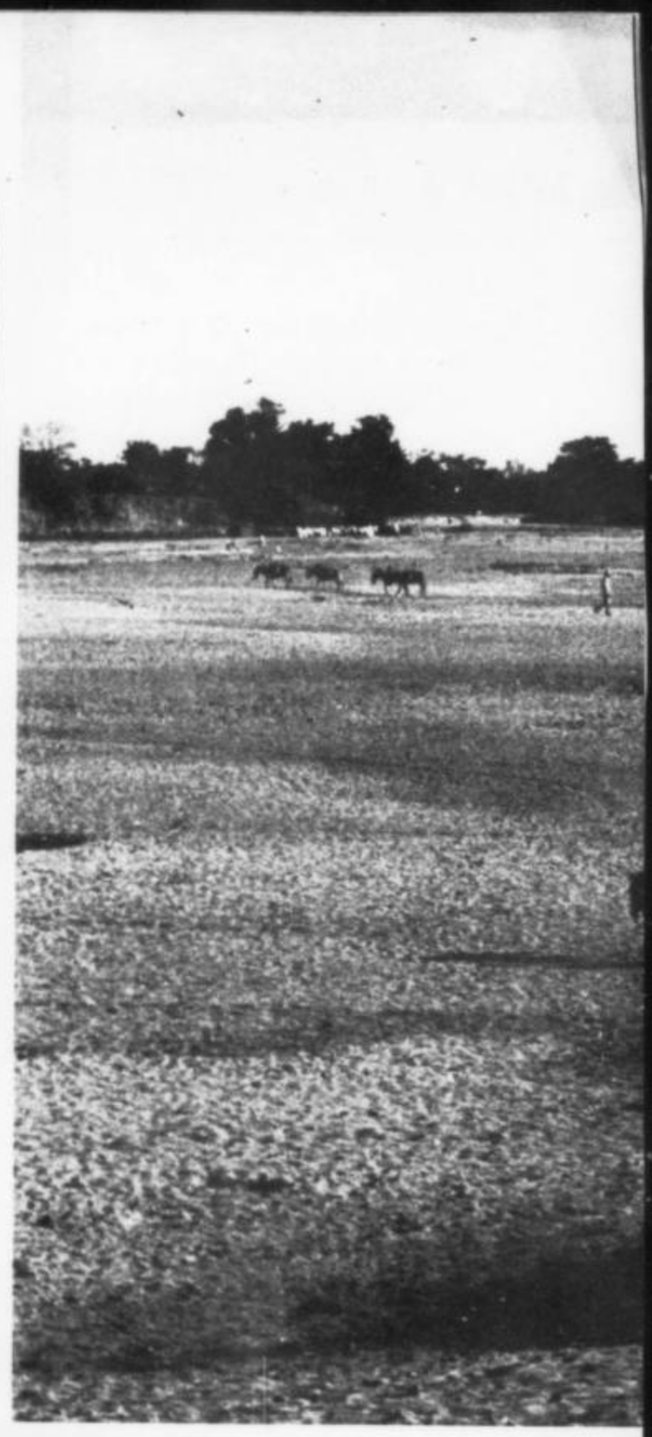

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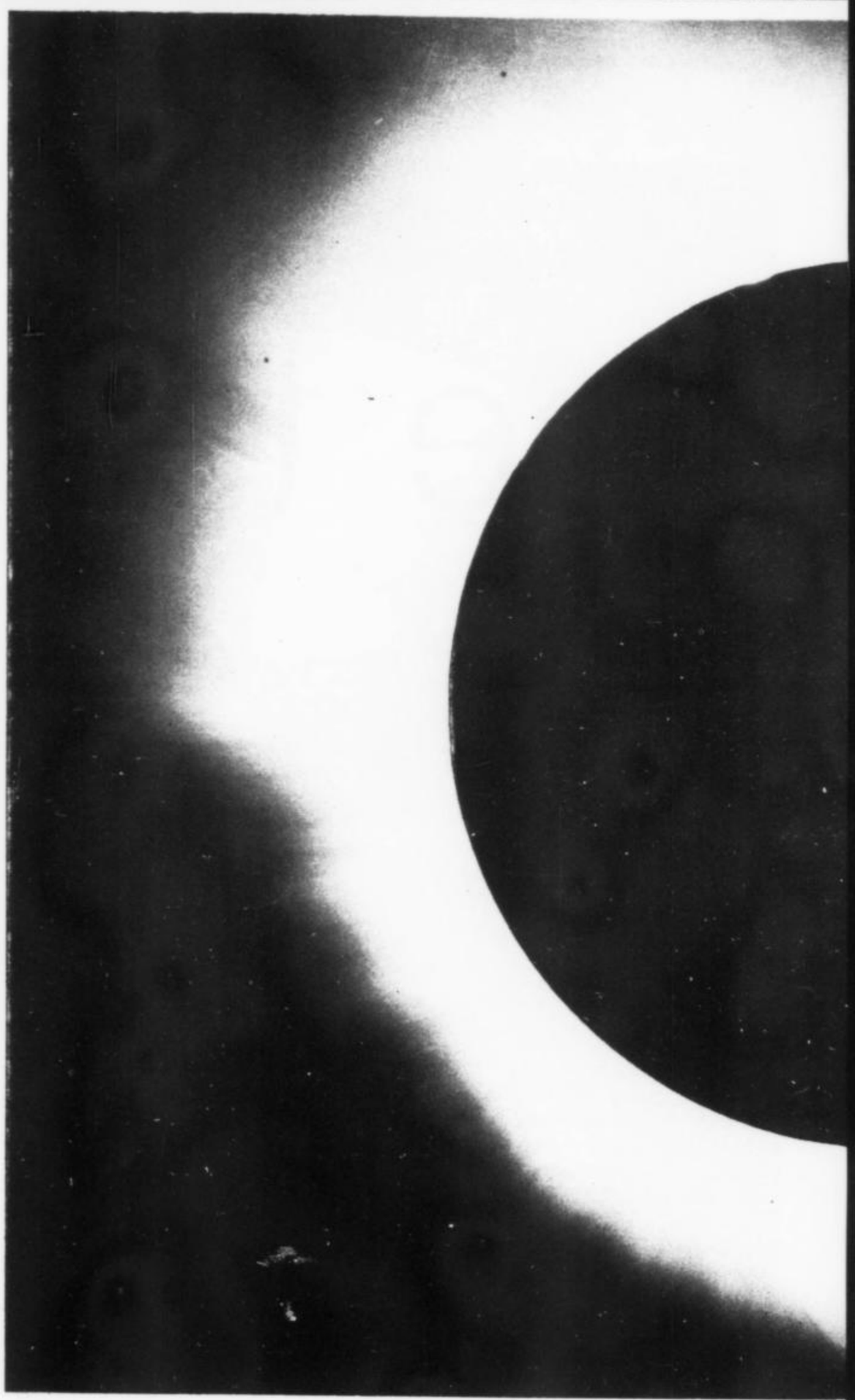

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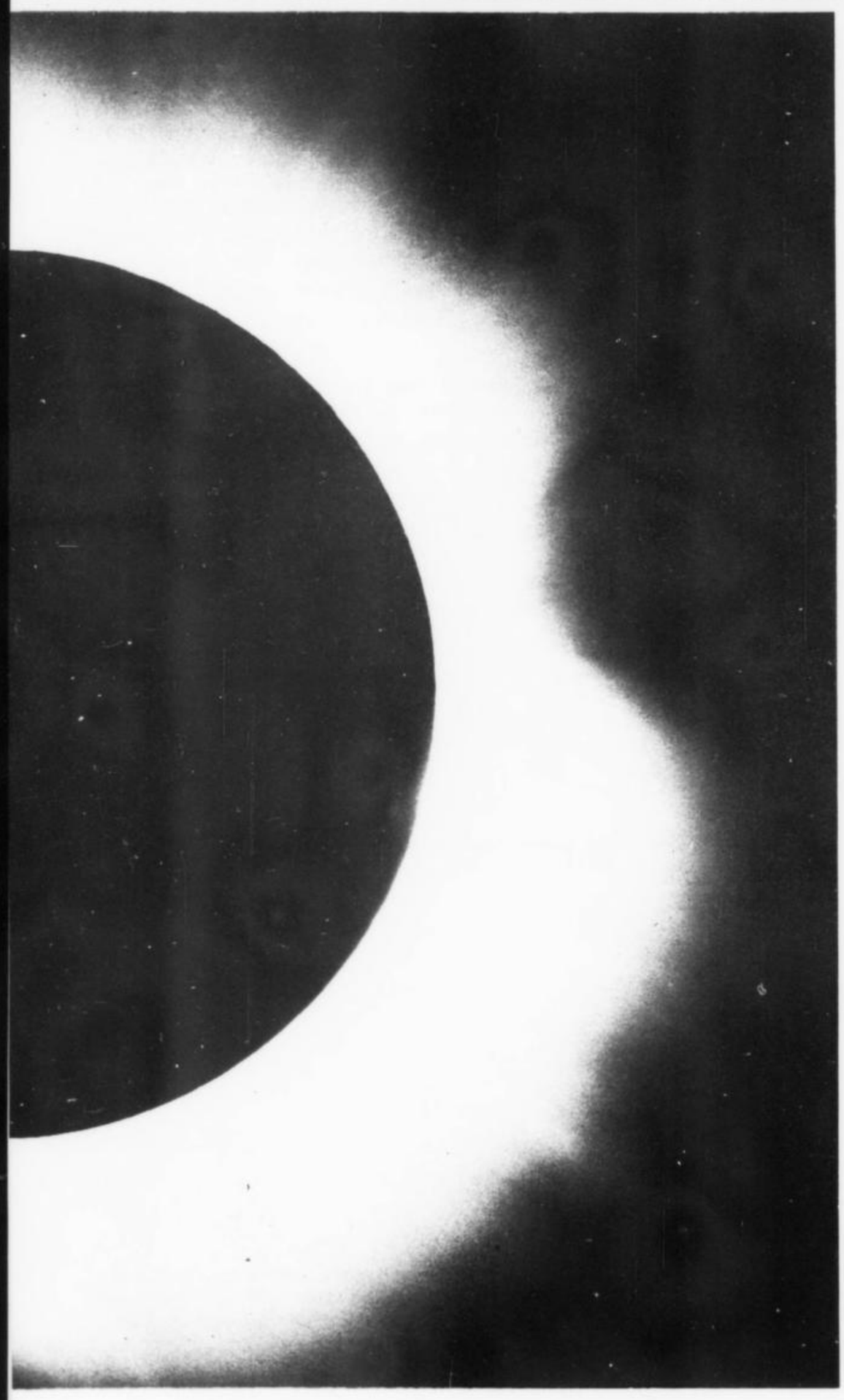
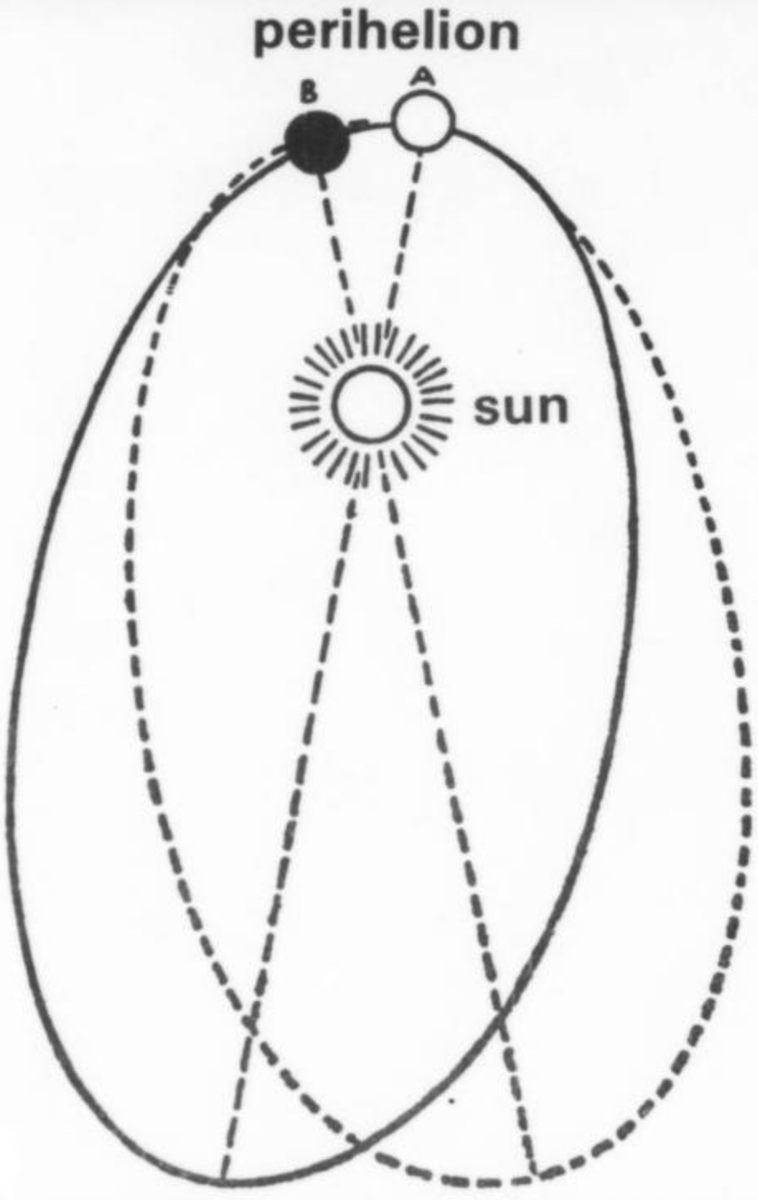
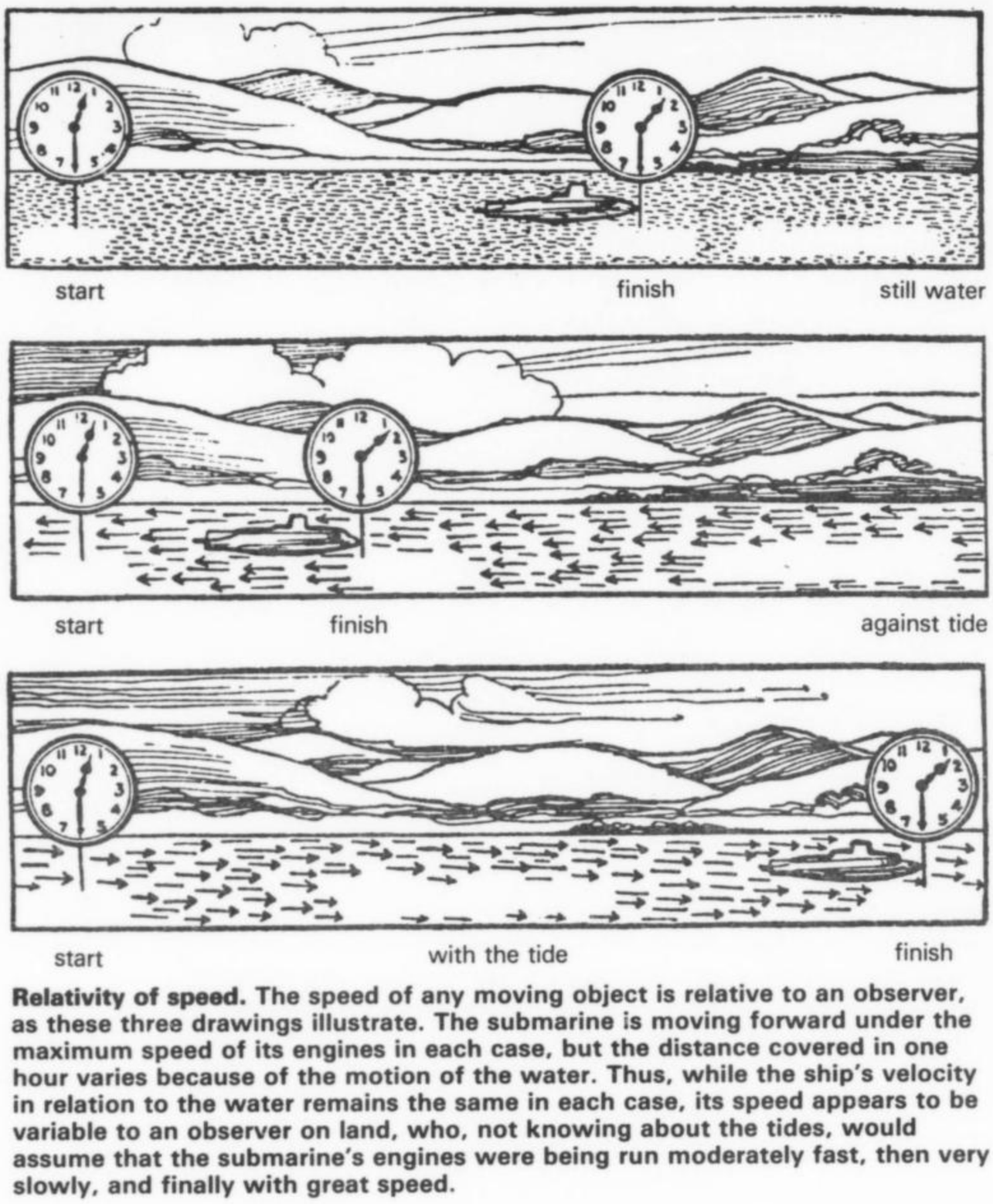


Light caught bending

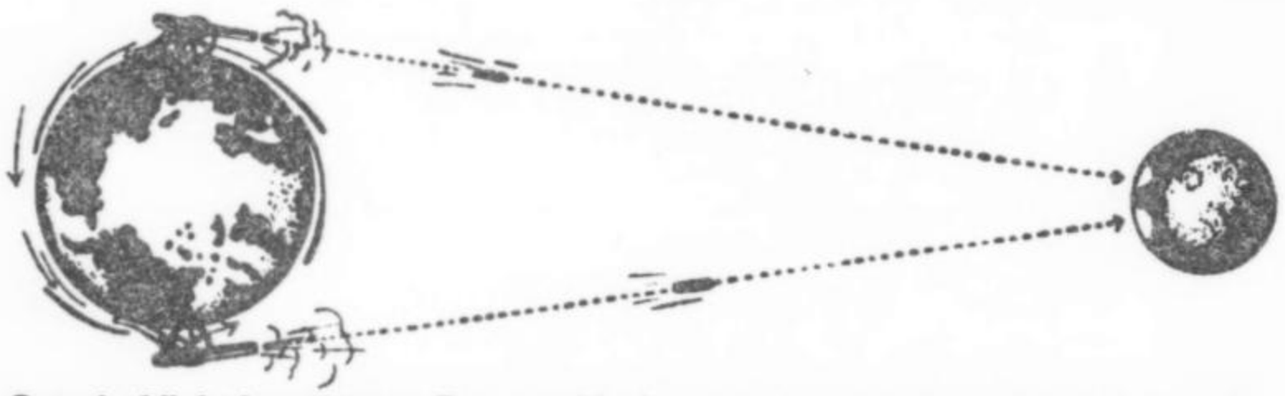
Perhaps the most famous and dramatic test of the General Theory of Relativity was carried out just sixty years ago under the direction of the British astronomer Arthur Eddington (1882-1944). In 1915, in the General Theory, Einstein predicted that gravity would bend the path of a ray of light when it passed near a massive star such as the sun. Eddington decided to test the theory during the total solar eclipse of 29 May 1919, for during a total eclipse it would be possible to take photographs of stars near the sun. These photos could then be compared with photos of the same stars taken when the sun was in a quite different part of the sky. Any difference between the positions of the stars in the two sets of photos would show that the starlight had "bent" and calculations could be made to show how much bending had occurred. The 1919 eclipse would be particularly propitious because it would take place in a region of the sky rich in bright stars that would be visible against the solar corona. Eddington organized two expeditions, one to Principe Island in the Gulf of Guinea, the other to Sobral in Brazil. Both expeditions were able to obtain sets of photos showing the positions of stars. Eddington, in charge of the African expedition, remembered his first measurements of the photos as the greatest moment of his life : they showed that the starlight had indeed been deflected. The Principe results showed a deflection slightly less than Einstein had predicted; those from Brazil rather more. On 27 September 1919, by which time the data had been more fully analysed, Einstein wrote to his mother : "Good news today... the British expeditions have definitely confirmed the deflection of light by the sun". Photos show 1) Einstein with Eddington at Cambridge in 1930. 2) The British astronomer Andrew Crommelin, who led the Sobral expedition, with some of the instruments used. 3) The solar corona during the 1919 eclipse. 4) A scene at Sobral during the expedition.



Mercury violates a cosmic schedule. Scientists were bothered for a hundred years because Mercury in reaching its perihelion, or point closest to the sun, did not revolve exactly once around the sun from one perihelion to the next. It seemed to exceed the celestial speed laws by travelling a little bit more. In the course of a century, this discrepancy amounted to forty-three seconds of arc, represented in the diagram by A...B. Einstein's explanation of this "aberration" was one of the outstanding results of his general theory of relativity.

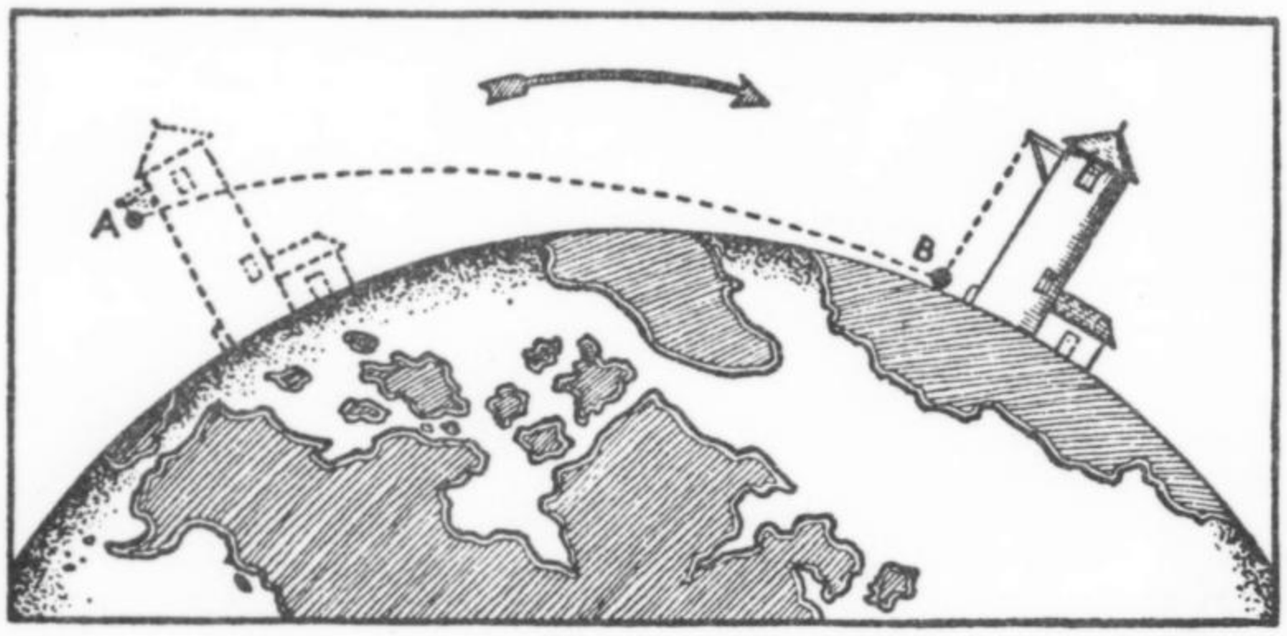


Relativity of speed. The speed of any moving object is relative to an observer, as these three drawings illustrate. The submarine is moving forward under the maximum speed of its engines in each case, but the distance covered in one hour varies because of the motion of the water. Thus, while the ship's velocity in relation to the water remains the same in each case, its speed appears to be variable to an observer on land, who, not knowing about the tides, would assume that the submarine's engines were being run moderately fast, then very slowly, and finally with great speed.



Speed of light is constant. Two mythical cannon at opposite ends of the earth fire a projectile at the moon. Because of a difference in speed due to the motion of the earth, the two projectiles arrive at their destination days apart. But the beams of light which appeared from each cannon at the same instant arrive at the moon simultaneously, exactly one and one third seconds after the firing of the cannon. The speed of light is not affected by any motion at its source or of the medium through which it passes, and for that reason is an important standard of measurement under the theory of relativity.

RELATIVITY IN PICTURES



Relativity of direction. What appears to us as a straight line may in reality be a curve. A person dropping a stone from the top of the tower sees it fall in a straight line to earth. But he forgets that the earth is moving. Because of this motion, an observer in space would see the stone fall not in a straight line but along the curved path A...B.

*Drawings and captions on these pages were done under Einstein's guidance. They are taken from **Albert Einstein Maker of Universes** by H. Gordon Garbedian © 1939 Cassell and Co. Ltd., London.*

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did not have the precision required for serious scientific discussion. Very little precise information was available. But still people were happy just to expound their views.

I was an engineering student at Bristol University in England at the time, and of course the students took up this subject and discussed it extensively among themselves. But neither the students nor the professors had precise information about it or knew anything about the underlying mathematics. We could only talk about the philosophical implications and accept the universal belief that it was a good theory.

In England, one man, Arthur Eddington, really understood relativity and became the leader and the authority on the subject. He was very much concerned with the astronomical consequences of the theory and the possibility of checking it by astronomical observations.

Three possible tests of the theory were proposed.

The first of these concerned the motion of the planet Mercury. The perihelion of Mercury (the point in the planet's trajectory nearest to the sun) was observed to be advancing about forty-three seconds of arc more than it should be according to the Newtonian theory, a fact that had been bothering astronomers for a long time. Einstein's new theory predicted just this effect and Eddington's tests confirmed this prediction.

This was really a wonderful success for Einstein's theory, but it is said that Einstein himself was not very excited when he heard of Eddington's confirmation because he felt that his theory had to be right in any case.

The second test concerned the deflection of light passing close by the sun. Einstein's theory of gravitation requires that light passing close by the sun shall be deflected. The Newtonian theory also requires a deflection, but only half the amount of the Einstein theory. So, by observing stars on the far side of the sun, whose light has passed close to the sun to reach us, we can test Einstein's theory.

Now we can only observe the stars close to the sun at a time of total eclipse, when the sun's light is blotted out by the moon. There was a suitable total eclipse in 1919 and Eddington prepared two expeditions to observe this eclipse, leading one of them in person.

Both expeditions obtained results which confirmed Einstein's theory. However, the accuracy of this confirmation was not very great because of the difficulties in making these observations. So people were not altogether satisfied with it. At many total eclipses of the sun that have occurred since then, people have again checked for this effect and they have always got results agreeing with Einstein's theory with a greater or lesser accuracy.

More recently it has become possible to check this effect with radio waves instead of light waves. Radio stars have been discovered and when a radio star is behind the sun we can observe whether the radio waves passing close by the sun are deflected. This can be done without waiting for a total eclipse because the sun is only a very weak emitter of radio waves. Using radio waves instead of light waves there is an added complication because radio waves are deflected by the sun's corona. But this deflection is different for waves of different lengths, so by making the observations for two different wavelengths, we can separate the effect arising from the corona from the Einstein effect. The result is that Einstein's theory is confirmed with an accuracy much greater than can be attained with light waves.

The third test concerned the prediction of the general relativity theory that light waves which have been emitted from a source in a gravitational field will be deflected towards longer wavelengths, i.e. towards the red end of the spectrum, an effect known as the red shift. The obvious place to look for this effect is with a light that has come from the surface of the sun. But it is difficult to observe the Einstein effect there because of another phenomenon (the Doppler effect) arising from the motion of the matter in the sun's atmosphere which is quite large and which is not very well understood. Nevertheless, we can make estimates of the effects of this motion and obtain a rough agreement of the requirements of Einstein's theory.

The discovery of the white dwarf star provides a better way of testing for this effect. With the white dwarf stars we have matter in a very highly condensed state. The gravitational potential at the surface of a white dwarf is very much greater than it is at the surface of the sun and the Einstein effect is correspondingly greater. If we have enough information about the white dwarf to be able to infer what its mass is and its size, we can get a very good check of Einstein's theory. This effect can now also be checked by laboratory observations with greater accuracy than we can get with astronomical observations.

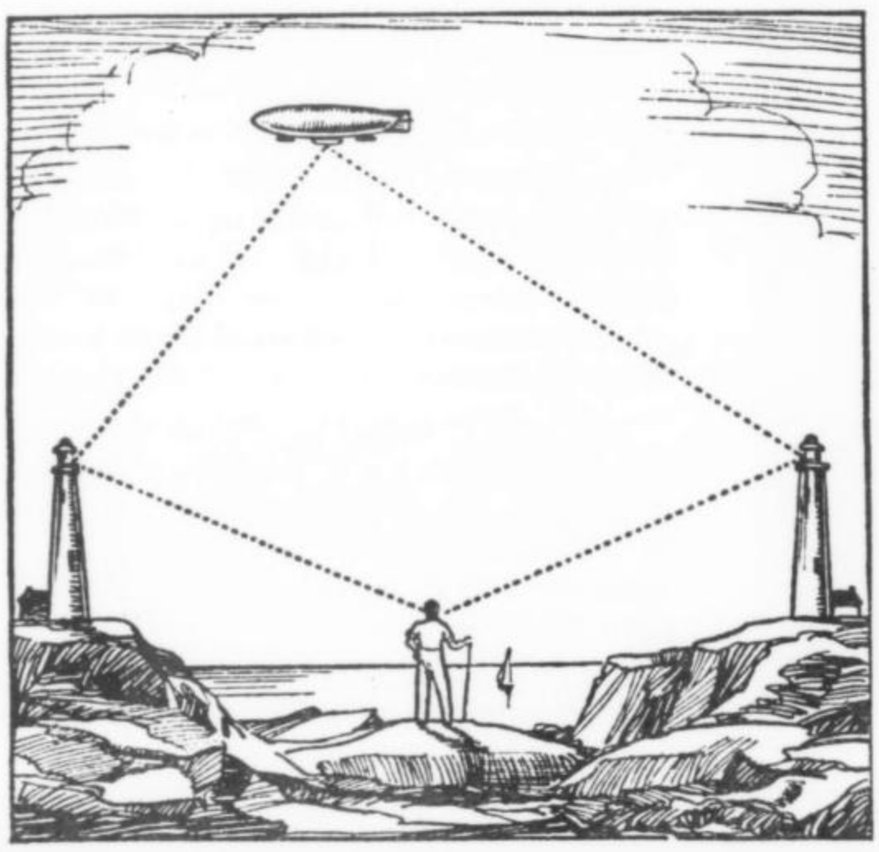
Recently a fourth test has been added to the three classical ones. This is concerned with the time taken by light to pass close by the sun. The Einstein theory requires a delay. This can be observed if we project radar waves to a planet on the far side of the sun, and then observe the time taken for the reflected waves to get back to earth. With the use of radar waves the retardation is affected by the sun's corona and again we have to use two different wavelengths to disentangle the corona effect from the Einstein effect.

The observations have been carried out by Irwin Shapiro and again there is good confirmation of the Einstein theory.

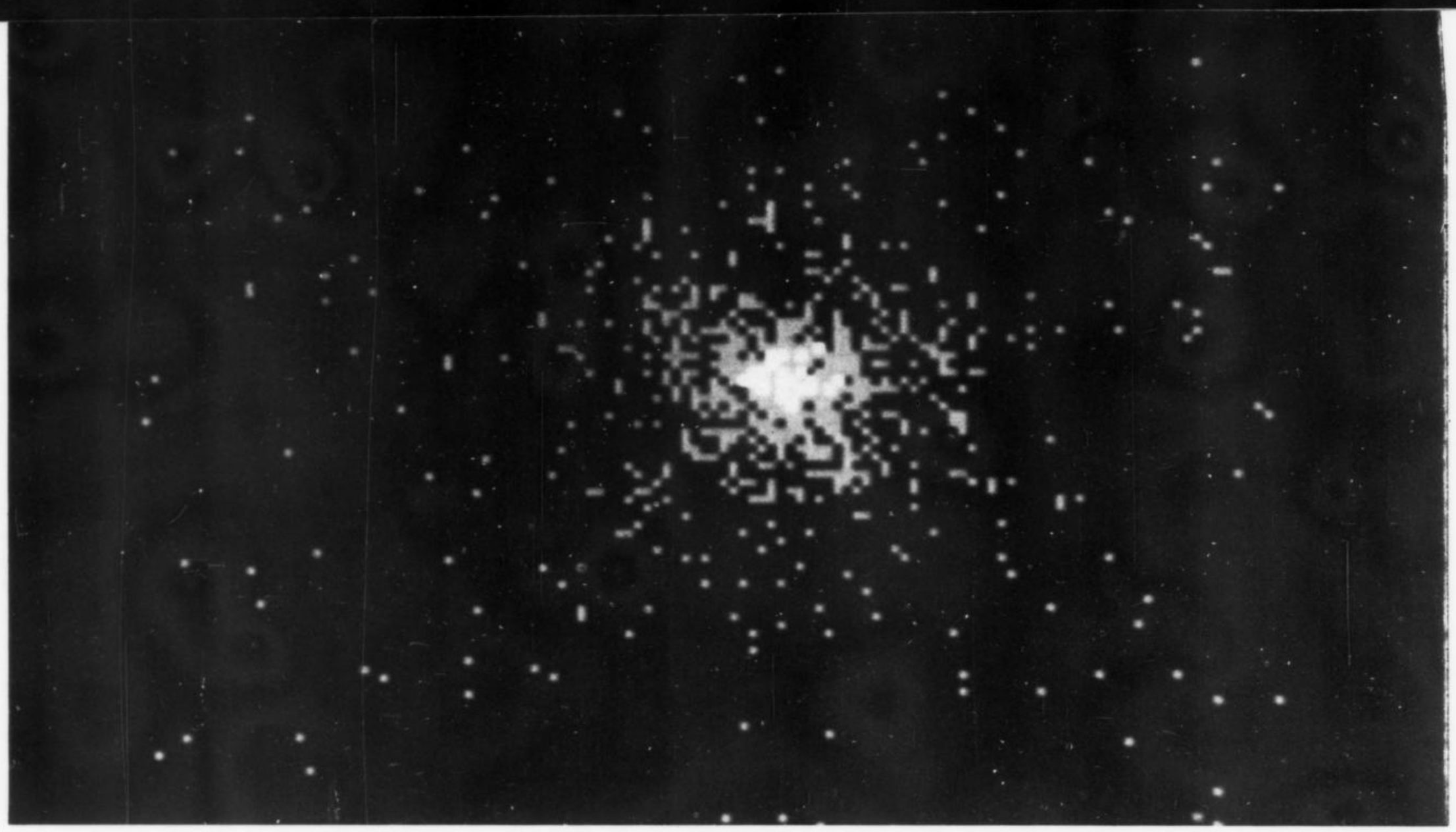
This enumeration of the successes of Einstein's theory is impressive. In every case Einstein's theory is confirmed, with greater or less accuracy depending on the precision with which the observations can be made and the uncertainties that they involve.

Let us now face the question, that a discrepancy has appeared, well confirmed and substantiated, between the theory and the observations. How should one react to it ? How would Einstein himself have reacted to it ? Should one then consider the theory to be basically wrong ?

I would say that the answer to the last question is emphatically No. Anyone who appreciates the fundamental harmony connecting the way nature runs and general mathematical principles must feel that a theory with the beauty and elegance of Einstein's theory *has* to be substantially correct. If a discrepancy should appear in some application of the theory, it must be caused by some secondary feature relating to this application which has not been adequately taken into account, and not by a failure of the general principles of the theory.

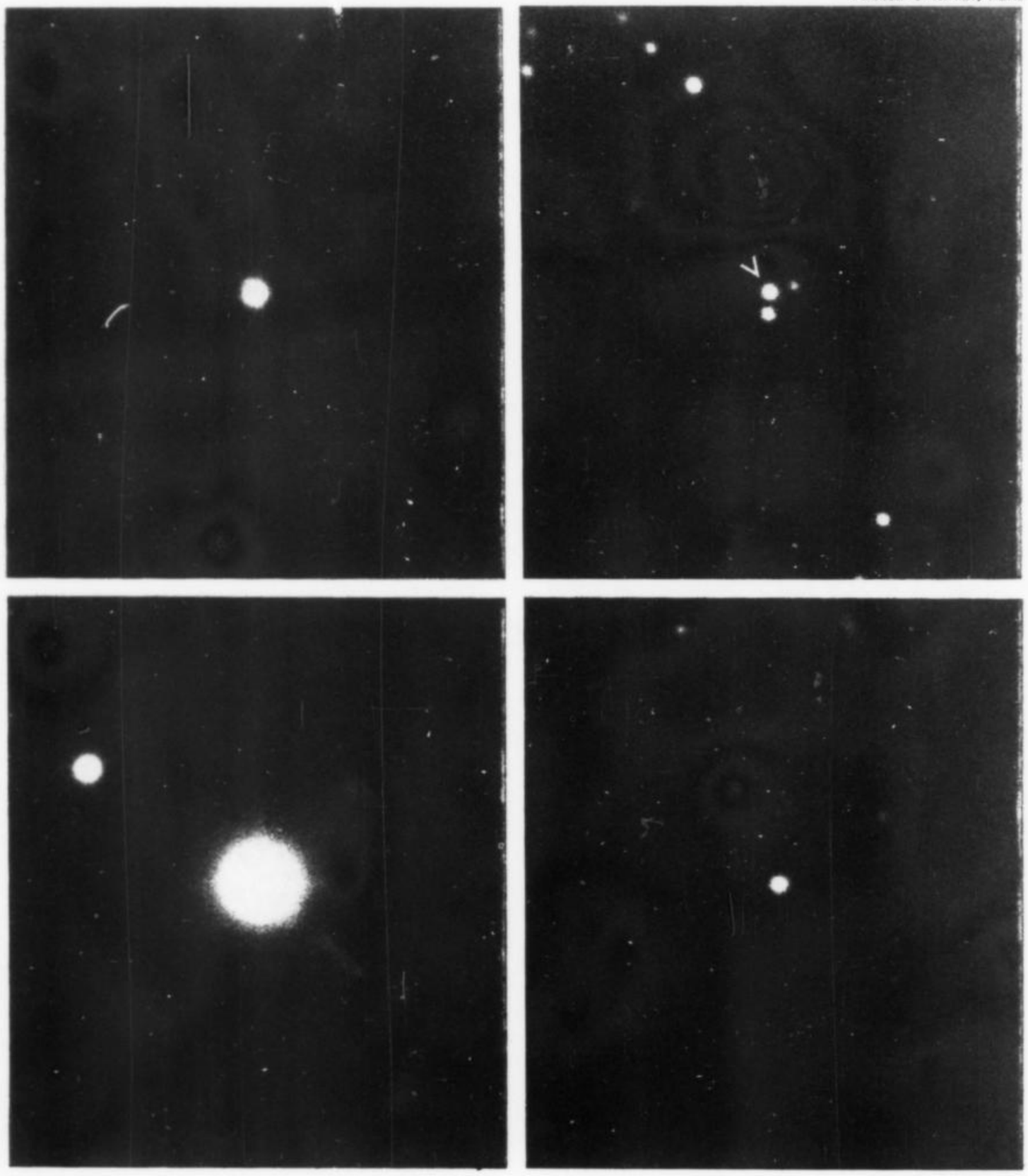


Relativity of time. Two widely separated lighthouses flash a warning beacon at the same instant. A man on the ground, exactly half-way between the two towers, sees the two flashes simultaneously. But to an observer in the airship, moving towards the beacon at the left, the two flashes would not be simultaneous. Relative to him, the flash from the tower nearest to him would appear a fraction of a second ahead of the other, as it has less distance to cover.



Above, the first ever picture of an X-ray star was transmitted from the three-ton orbiting space observatory HEAO-2. The star is called Cygnus X-1. It is part of a dual system in the Cygnus constellation about 6,000 light years away. This dual system is believed to contain a black hole (see page 15). Below, four quasars photographed through the Hale telescope at Mount Palomar in California. Quasars (quasi-stellar radio sources), celestial bodies that emit radio waves, were first discovered in 1962. Some quasars also emit X-rays. The quasar known as 3C-273 (lower left) is the most powerful X-ray source so far discovered.

Photos © I.P.S., Paris



When Einstein was working on building up his theory of gravitation he was not trying to account for some results of observations. Far from it. His entire procedure was to search for a beautiful theory, a theory of a type that nature would choose.

He was guided only by the requirement that his theory should have the beauty and the elegance which one would expect to be provided by any fundamental description of nature. He was working entirely from these ideas of what nature ought to be like and not from the requirement to account for certain experimental results.

Of course it needs real genius to be able to imagine what nature should be like; just from abstract thinking about it. Einstein was able to do it.

Somehow he got the idea of connecting gravitation with the curvature of space. He was able to develop a mathematical scheme incorporating this idea. He was guided only by consideration of the beauty of the equations.

The result of such a procedure is a theory of great simplicity and elegance in its basic ideas. One has an overpowering belief that its foundations must be correct quite independent of its agreement with observation.

I had the privilege of meeting Einstein on various occasions. The first time was at the

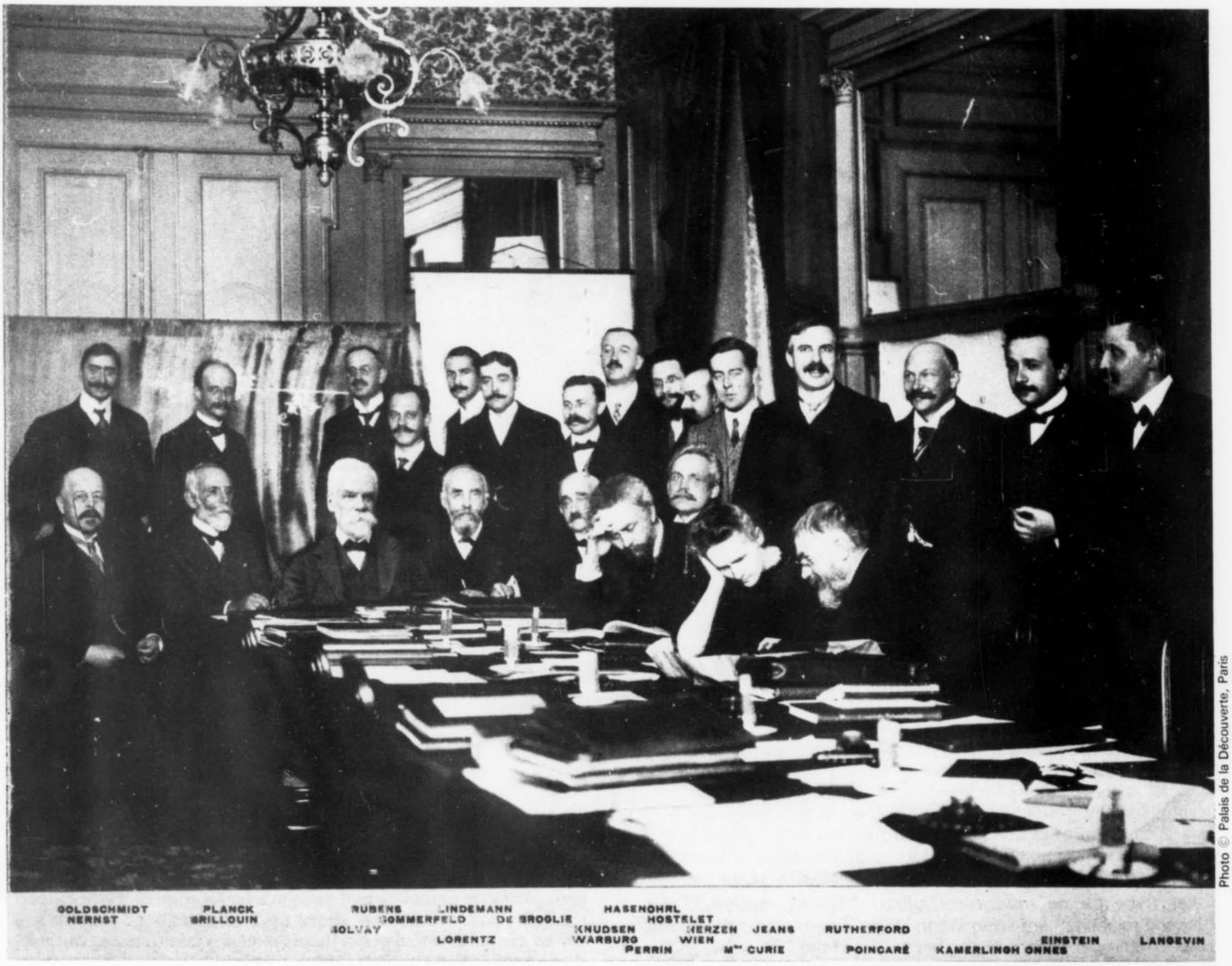


Photo © Palais de la Découverte, Paris

The first Solvay Conference (so named after the Belgian industrialist Ernest Solvay who sponsored it) was held in Brussels in 1911 to discuss the consequences of Max Planck's law of black body radiation, formulated in 1901, which laid the foundation of the quantum theory. This group of scientists, perhaps the most prestigious ever gathered together, was responsible for advances in knowledge that form the basis of modern physics.

Solvay Conference in Brussels in 1927 at which the leading scientists of the world discussed recent developments.

By that time Einstein's theory was firmly established and generally accepted and it was not a subject of discussion at that conference. The major topic was the new quantum theory of Heisenberg, Schrödinger and others. Of course, we all wanted to have Einstein's impressions of the new ideas.

Einstein was a little hostile to these ideas because he had obtained such a marvellous success with his own ideas of introducing geometry into physics and he thought that further development would also be on the lines of introducing more exotic kinds of geometry. He had spent many years of his life working on those lines without any very substantial success. Probably these ideas of Einstein are basically correct but they have not yet led to a satisfactory solution.

I also met Einstein at a later Solvay Conference; then he came to Cambridge, where I was working, and later went to Princeton and became a permanent member of the Institute for Advanced Study. I was also a temporary member of the Institute from time to time.

I attended lectures which Einstein gave and sometimes he invited me to his house which was a great privilege. I got to know him personally on those occasions. I was able to see how scientific ideas dominated pretty well all his thoughts; even when you were given a cup of tea and you stirred it, the motion of the tea-leaves was something which Einstein figured out how to explain.

During the course of Einstein's discussions with physicists, he made one remark which has become very famous and is now carved into the stonework over the fireplace in the common-room of the Mathematics Institute at Princeton University. To appreciate this remark you really have to be a research physicist and understand that God has set certain problems which the research physicist is trying to solve. Furthermore, you must try to appreciate the mentality of God in setting these problems. Einstein summed up his view of this situation with these words : "Raffiniert ist Gott, aber bosartig ist Er nicht", "God is clever, but not dishonest".

■ **Paul Dirac**

The mole and the butterfly

Reflections on Einstein, science and subjectivity

by Pierre Thuillier

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"IF we consider science as a completed body of knowledge, it is the most impersonal of human works; but if we see it as a continuing project, it is just as subjective and psychologically conditioned as any other human undertaking." This declaration of Einstein's may surprise the defenders of a certain form of logical positivism. But it constitutes a sort of invitation to scrutinize the "subjective" genesis of relativistic ideas.

Let there be no misunderstanding. "Special relativity" and "general relativity" are *scientific* theories; only by considering the state of physical science at the beginning of the 19th century can we understand the nature of these theories and evaluate their importance. If our only interest lies in the "progress" of knowledge *per se,* we may even feel justified in ignoring (or condemning as too anecdotic) all psychological or sociological contributions to the history of science. The fact remains that Einstein himself was always at pains to analyse his ideas and the influences he had undergone.

Let us seriously consider the objection implied above that science is essentially "objective", or at least is only of value insofar as it is "objective". If this is so why deliberately place so much importance on the "subjectivity" of the scientist, even if his name is Einstein? In other words, it would be ill-advised and even dangerous to confuse art and science. Artists do not seek to describe reality "as it is": they interpret it and reconstruct it according to the dictates of their sensitivity and imagination. But scientists, we are given to understand, go about it quite differently; they prefer to silence their "subjectivity" and listen only to the "voice of facts"; relying on a strict methodology they succeed in establishing perfectly precise "laws of nature".

According to this view of science, what counts is that the concepts be precisely defined and workable and the results confirmed experimentally. Scientific "geniuses" are, undoubtedly, remarkable in their own way: but their work would seem to have nothing "subjective" about it.

This approach has all the appearances of everyday common sense. However, it may well conceal the difficulties inherent in the notion of objectivity. No one would dream of denying that scientific statements must be able to stand up to experiment. But even when the "verdict of the experiment" is favourable, can it really be said that the theory's "objectivity" has been established?

In fact, only the value (or validity) of the theory has been confirmed. Strictly speaking, a positive result does not prove that the statements tested are absolutely "true". For another theory may turn out to be as good or even better. In other words, one is never sure of having complete and definitive knowledge of the "objects" studied. Experiments can show that, *in certain conditions and within certain limits,* a given theory explains phenomena. But they do not prove that this knowledge is absolute and completely true.

Examples abound. Thus, for a long time it was thought that Newton's mechanics offered a strictly accurate ("objective") description of nature. But it is this very idea that the theory of relativity calls into question. We must admit that science aims at giving an objective description (or explanation) of phenomena. But it would be going too far to assert that scientific theories, such as they exist in reality, are wholly objective constructions, that is to say, devoid of any "subjective" element. It is for this very reason that theories are constantly evolving.

The approach adopted to the problem of subjectivity in science is closely linked to the solutions given to certain purely epistemological questions (questions concerning the nature and value of scientific knowledge). Einstein himself was well aware of this, as is attested by his analyses concerning the connexion between "facts" and "theories".

Newton, he said, believed that "the laws and basic concepts of his system could be derived from experiment". But this is not so. Contrary to what some empiricists think, "any attempt logically to deduce concepts and fundamental postulates from elementary experiments is doomed to failure". In fact, the foundations of theoretical physics must be "freely invented". Which means that to develop their science physicists do not passively record sense data, but build a theoretical framework with the aid of principles and concepts that they have not only selected, but, as Einstein repeated time and again, freely selected.

This view could be described as constructivistic. Not only does it allow that the theoreticians' "subjectivity" is involved, it also admits that this involvement is practically unavoidable and entirely legitimate. True, some theories are better than others. But, as Einstein observes, "there is no logical bridge between phenomena and the principles intended to explain them". But if these principles do not stem from the phenomena, then what is their source?

Einstein's view can be summarized as follows: although the scientist seeks to give a "rational" image of the world, he has no

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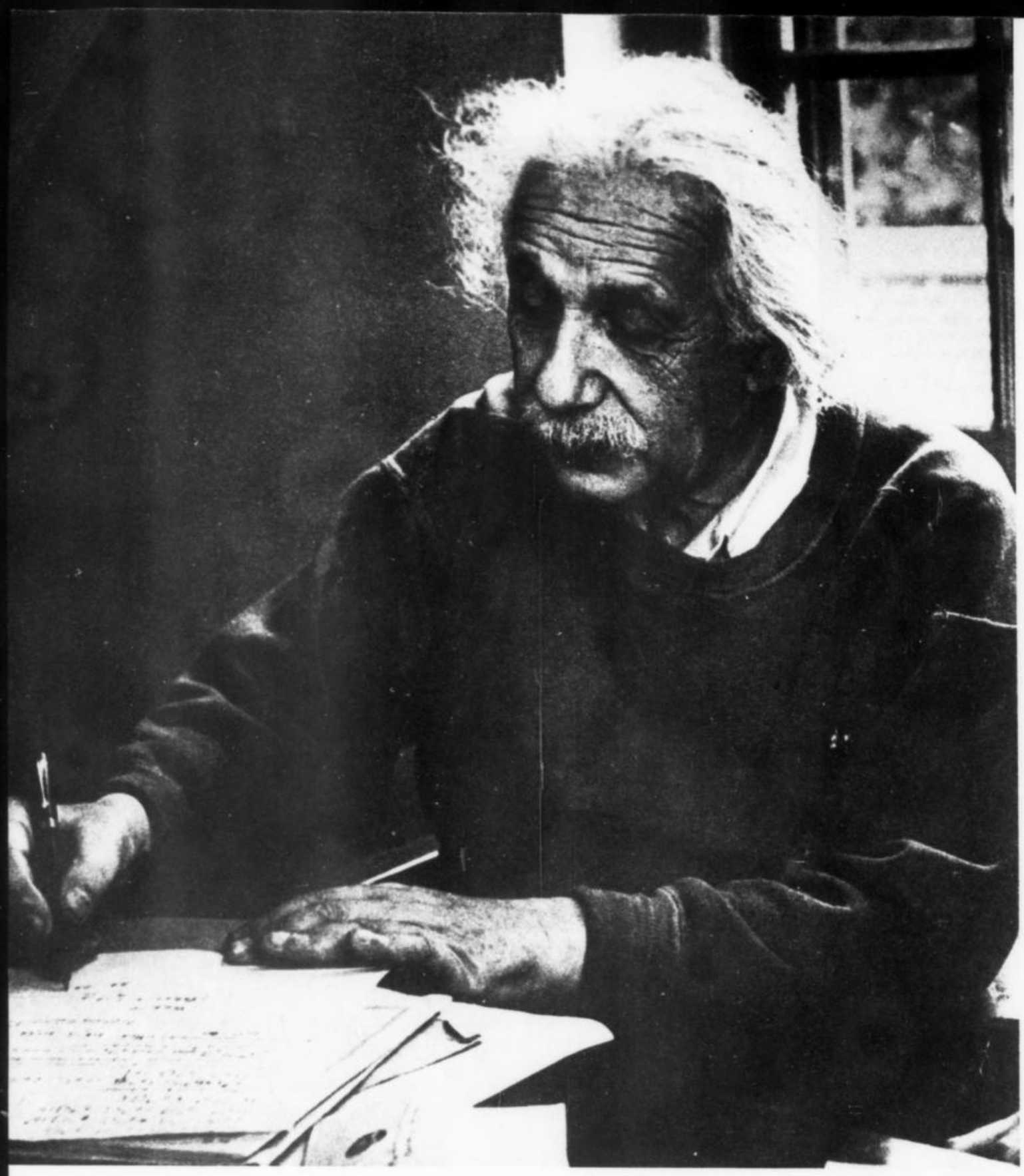


Einstein at his desk at Princeton University in 1948. When someone once asked him where his laboratory was he took a fountain pen out of his breast pocket and said : "Here".

Photo © Parimage, Paris

access to unique and absolute Reason which will present him, in a purely logical way, with the concepts and principles he needs. It is by using their own resources and their own experiences that men try to invent intellectual tools that are more or less suited to "reality". So the genesis of scientific theories lies not only in logic and epistemology, but in psychology, sociology and cultural anthropology.

The so-called advanced societies propagate an image of science which, more than anything, emphasizes its stringent, logical, "objective" aspects. But Einstein, both by his declarations and his scientific activity itself, gives us a wonderful opportunity to get a better look at the reverse side of this image with its concomitant emotions, flights of fancy, philosophical convictions, even "mystical" passion.

We know that Einstein and Michele Besso enjoyed a long friendship. One day Besso's sister asked Einstein: "Why hasn't Michele made any major discovery in mathematics?" Einstein laughingly replied: "But that's a very good sign. Michele is a humanist, a universal spirit, with too much interest in too many things to become a monomaniac. Only a monomaniac gets what one calls 'results'." Urged by Besso to explain, he went on: "I still believe you would have developed significant ideas in the field of science if you had been obsessive enough. A butterfly is not a mole, but no butterfly should mind that".

And so it would be nice to know: to what extent was Einstein a "mole", a "monomaniac"? What was the obsession that could more or less directly engender special relativity and general relativity? In answer Einstein suggests: the real scientist is totally imbued with "cosmic religious feeling".

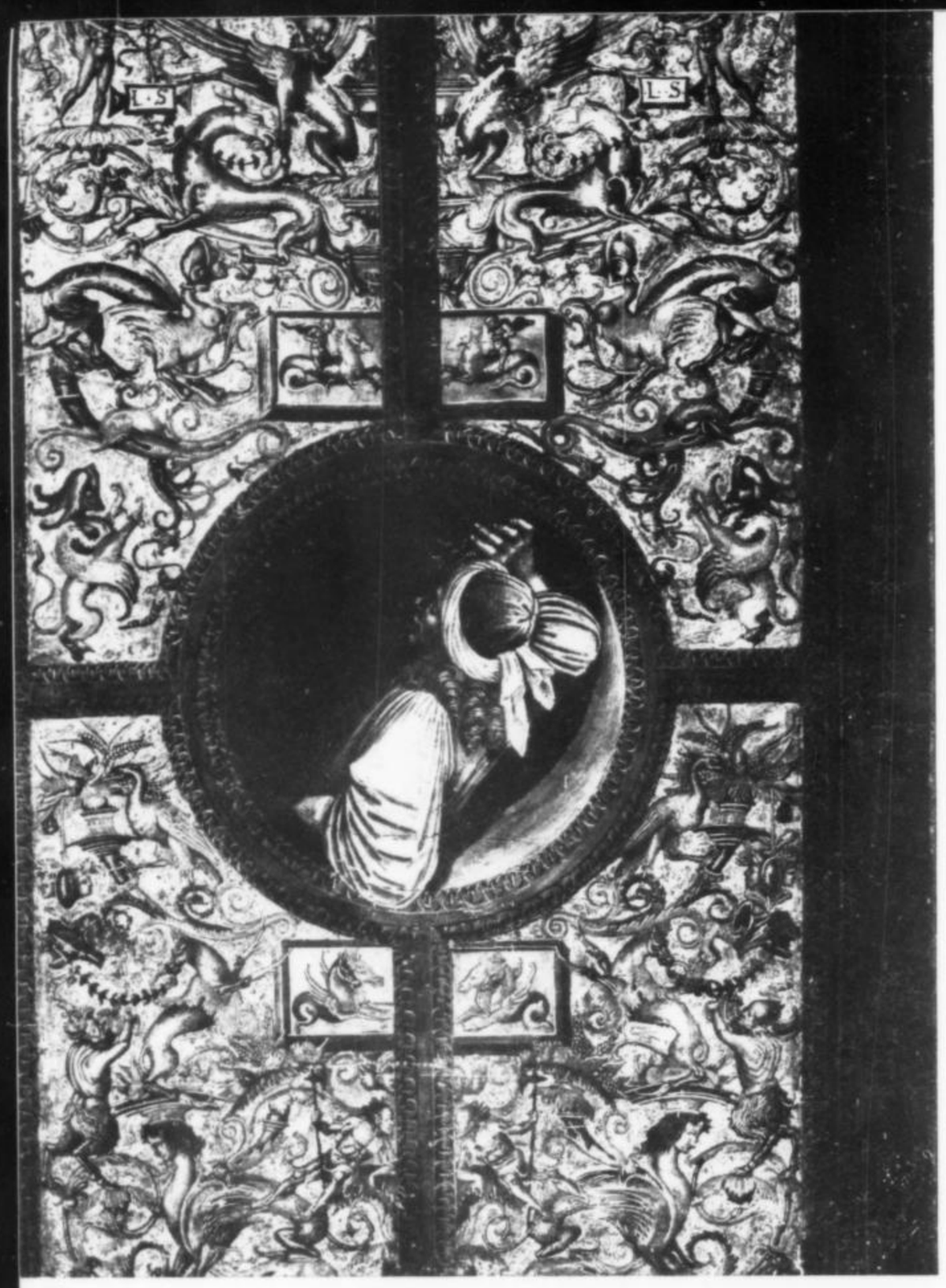
According to him, this is the third degree of religious life, the first two being religion-fear and religion-morals, in that order. "I maintain (...) that cosmic religiosity is the strongest, most noble incentive to scientific research. Only someone who can measure the enormous efforts and, even more, the dedication without which scientific creations opening up new ways cannot be realized, is in a position to appreciate the strength of feeling which alone can engender a work of this kind, detached from everyday living. (...) It is cosmic religious feeling that gives man this strength".

So on this point Einstein thinks very differently from the positivists: "In our materialistic age, serious scientific researchers are the only men who are deeply religious". Remarks like this are two a penny in Einstein. Sometimes we even get the impression that he is rather overstating his idea: "I cannot imagine a genuine scientist who does not have deep faith. The situation can be summed up in a metaphor: science without religion is lame, religion without science is blind".

A few observations on this Einsteinian religion would not come amiss. First of all, it has no connexion with religions which accept the existence of a personal God who dispenses punishments and rewards. Einstein feels that this sort of doctrine is impure and that religions should reject it out of hand. True, the idea of a personal God breeds hopes and fears and gives priests enormous power over the minds of men. But in the long run it can only cause "incalculable harm to the progress of mankind". Therefore Einstein prefers to call himself a pantheist. To be religious is to endeavour in all modesty to understand the order of the world.

In this way Einstein makes an almost systematic connexion between the idea of "religion" and the idea that the world is intelligible and rational. More precisely, the scientist must believe that the world is so. If he is brave enough to dedicate himself to the study of nature, it is precisely because he is convinced that nature is constructed according to harmonious laws.

For Einstein this means, among other things, that everything is determined by strict causality. The real scientist thinks "that causal law determines all events", from which it is easy to understand why he cannot accept the idea of a personal God, that is a being who dictates the course of events. In his own way, Einstein is very lucid. Instead of using causality as absolute evidence, he makes it the object of religious belief, of personal commitment. This



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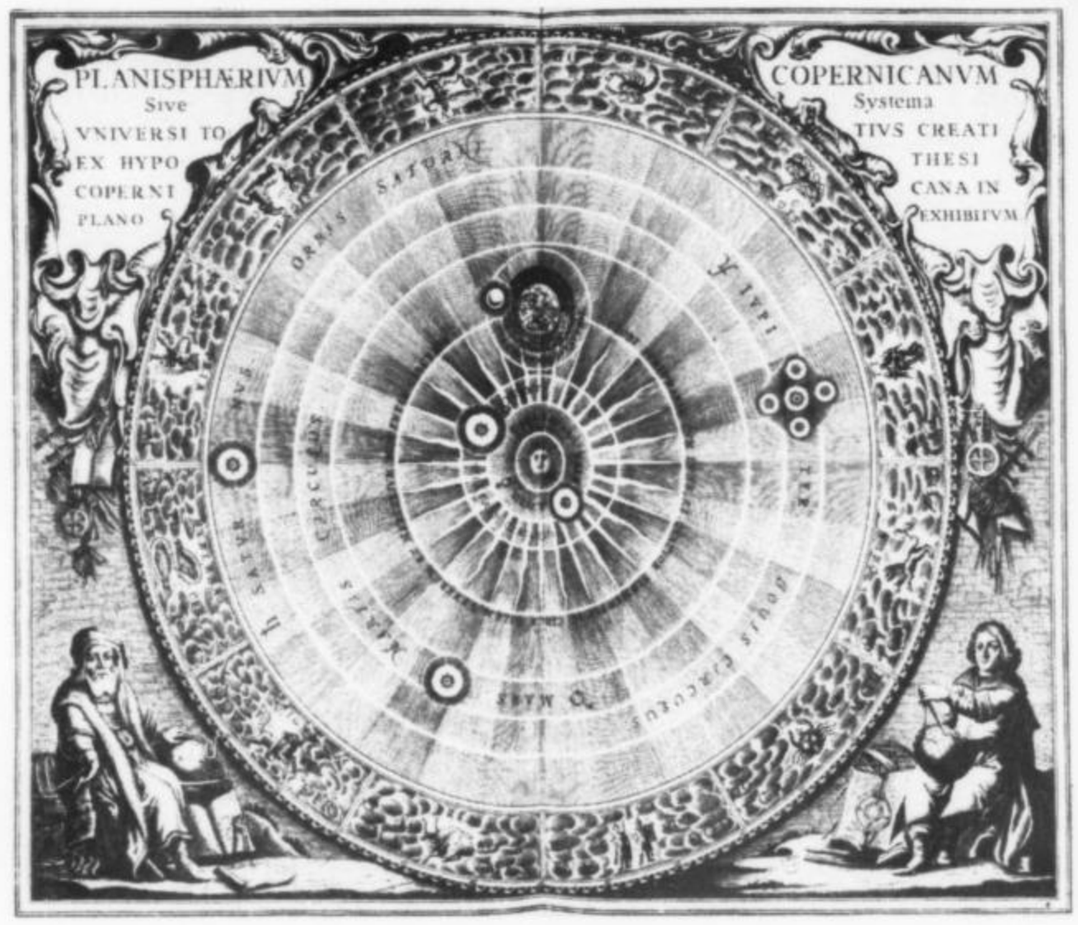

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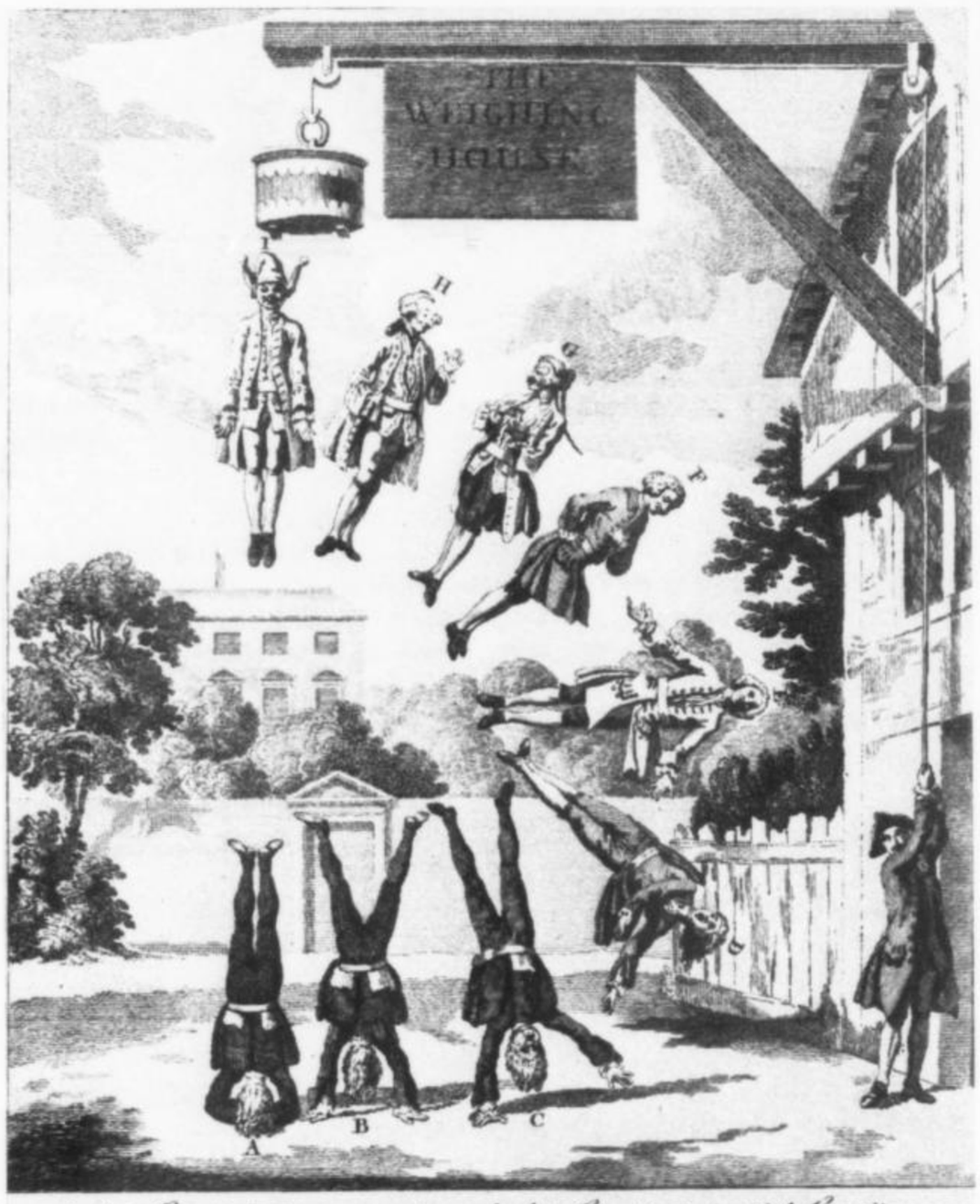


A. *absolute Gravity.* B. Conatus *against absolute Gravity.* C. *partial Gravity.* D. *comparative Gravity* E. *horizontal, or good Sense.* F. *Wit.* G. *comparative Levity or Gravity.* H. *partial Levity, or pert Fool.* I. *absolute Levity, or Stark Fool.* — 4

From Empedocles to Newton: a constellation of

The work of the Greek philosopher Empedocles (490-430 BC) is a milestone in the history of Western thought because, not relying on the intervention of divine or supernatural forces, he imagined a universe consisting of four basic substances — fire, air, earth and water — combined in various proportions.

Like the ancient Babylonian astronomers whose observations had come down to them, the Greeks of Antiquity believed that the earth was the centre of the universe. This idea was central to the work of the great astronomer Hipparchus, who around 150 BC discovered the precessional movement of the equinoxes. This means that each year the so-called "equinoctial point" at which the sun crosses the equator shifts slightly westward. The ideas of Hipparchus were taken up and developed by Ptolemy (c.90-168 AD) one of the greatest astronomers and geographers of Antiquity, whose system of cosmology was to dominate Western thought for over a thousand years.

His work is preserved in a compendium known as the *Almagest*, a composite Greek-Arab term meaning "the greatest". In it Ptolemy constructed an elaborate model of the heavens composed of large circles, called deferents, and small circles, called epicycles. Each planet rode on the circumference of an epicycle, the centre of which revolved on the deferent. From the Hellenistic Age until the Middle Ages, this system of epicycles and deferents remained, with some modifications, "the last word in astronomy". The earth was immovable, fixed by God in the centre of the universe beneath the concave dome of the stars.

Then in the 15th century, the Polish doctor, jurist and astronomer Nicolaus Copernicus (1473-1543) set out to perfect the Ptolemaic system. However, as his studies progressed, he became increasingly dissatisfied with Ptolemaic astronomy, and his calculations were to lead him to a radically different picture of the universe. Ptolemaic astronomy left certain phenomena

evidently does not prevent him in practice from using the principle of causality as a decisive criterion in evaluating scientific theories.

So it was that he consistently refused to recognize the legitimacy of quantum mechanics. For "God does not play dice". With this oft-repeated formula Einstein declared his faith in a rigid determinism of natural phenomena. He could not accept "the statistical craze" as evinced in the speculations of the Bohrs, Borns, Heisenbergs and Paulis.

The major stumbling-block of quantum theory, in his view, is that it does not provide a complete description of reality ; "probabilities" cannot be the last word in knowledge. The Einstein/Born correspondence is eloquent on this point: Born never succeeded in shaking Einstein's "cosmic religion"—Einstein found it shocking that a particle might be considered not to behave in a totally predictable way.

But the belief in universal causality is rather commonplace: it could never on its own have "inspired" the theory of relativity. On the other hand, it is quite remarkable that Einstein often defined his "religious" position by contrasting "the inanity of man's longings and objectives" with nature's "sublimity" and "wonderful order".

Individual existence is a "kind of prison". So the quest for knowledge has a thoroughly fundamental significance: man, as an individual, does not amount to much, but he has the capacity to contemplate and understand the universal order. Through knowledge "the individual endeavours to experience the universe as an entity with a meaning". A religious man is a man who has, as far as he can, freed himself of the trammels of selfish desires, and turned towards thoughts, feelings and aspirations of supraperso-nal value.

In his *Autobiographical Notes,* Einstein returns to this theme: we must "free ourselves from the shackles of the purely personal" and endeavour to discover an "extra-personal world" which will constitute a new paradise. Thus is established the existence of a "real world", independent of ourselves, the contemplation of which has (or will have) a liberating effect.

Einstein's epistemological realism, we see, is deeply and directly rooted in his "subjectivity". And here we are in a position to advance a crucial hypothesis: if Einstein worked out special relativity and general relativity, it was precisely in order to enjoy a world that is more real and more satisfactory than the poor world in which we live from day to day.

What is in fact the essence of the "theory of relativity"? It is sufficient to read Einstein to realize that, despite its name, this theory expresses the wish to find "laws of nature" the form of which remains constant regardless of the system of reference adopted. Special relativity only applies to the Galilean systems, that is to say, systems in which there is validity for "the fundamental law known as the law of inertia: a body sufficiently removed from other bodies persists in its state of rest or uniform rectilinear motion". The general theory of relativity can be expressed as follows: "All systems of reference, regardless of their state of motion, are equally valid in the formulation of the general laws of nature."

To put it more simply, let us say that the theory of relativity represents the wish to find an image of the world independent of the position of different observers. For some time now various authors have been struck by the fact that a "postulate" of this sort quite faithfully reflects Einstein's personal ideas mentioned earlier on. Everything seems to point to the fact that relativistic physics is the realization, in a particular field, of a more general programme: to build a "suprapersonal" world, a world situated beyond our sensations and perceptions but possessing a superior reality.

The detractors of the new theory were not mistaken; they clearly perceived that relativistic speculations were by no means founded on pure and simple "objectivity". So we have Christian Cornelissen, in a little book published in Paris in 1923, deploring Einstein's hallucinations. He regretted that Einstein had taken certain ideas "to the absurd" and "let himself stray into the realm of metaphysics". In a way he was right! To dare to formulate such theories, Einstein had to be (there is a tendency to forget this nowadays) extraordinarily confident about various presuppositions which were by no means evident. It is not surprising that less daring minds than his at the turn of the century were hard put to share this "faith".

Einstein displayed his originality in the article published in 1905 in which he laid the foundations of the theory of relativity. But this originality lay not so much in the novelty of the ideas he used as in the way in which he deployed them.

The French mathematician Henri Poincaré had seen quite clearly the new uses to which the "theory of relativity" could be put, while the Dutch physicist Lorentz developed the "transformation" which bears his name—and the formalism of which was adopted by Einstein. So much so that Sir Edmund Whittaker, an Englishman and author of the authoritative *History of the Theories of Aether and Electricity,* could attribute the theory of relativity to Poincaré and Lorentz, which rather shocked Max Born. In fact, far from being the fathers of this theory, neither Poincaré nor Lorentz ever really accepted it. Whittaker's mistake is both a psychological and an epistemological one: he underestimated Einstein's intellectual courage, what could be called his philosophico-scientific radicalism.

For Poincaré probably understood the theory of relativity as well as Einstein did. But he thought of it as being only "a convention suggested by experience". Physicists, he said, could well do without it. In other words, Poincaré hesitated to demolish the classical theory. This sort of timidity is quite foreign to Einstein. He makes no bones about it. He decides that the "theory of relativity" is a *sine qua non* if one is to rebuild the theoretical edifice from scratch. At least temporarily, it must not be called into question.

Therein lies all the difference between the two: Poincaré adopted a conservative strategy while Einstein decided to pioneer an entirely new path. Hence the importance of being a "monomaniac". For intelligence was not enough to invent the theory of relativity; one also had to be "mad" to select the new bases despite their paradoxical nature.

In his 1905 article Einstein showed his audacity by admitting two basic principles from the outset: the principle of relativity (which has just been discussed) and the principle of the constancy of the speed of light. It was all the more daring since, according to Einstein himself, these two principles were apparently incompatible. This raised certain questions: how did Einstein get the idea of asserting the constancy of the speed of light?

Many physicists and philosophers felt that Einstein had been led

cosmologists

unexplained. Why, for example, did certain planets seem to stop and move backwards and forwards in a loop ? Copernicus audaciously wondered whether such movements of the planets might not be explained in terms of the movement of the earth. "All the visible movements of the sun and the planets", he wrote, "are not thus in themselves but only as seen from the earth".

Copernicus' great treatise on the movements of the earth and the other planets was not published until 1543, the year of its author's death. It attracted immediate criticism and was soon put on the Church's Index of prohibited books. It was many years before the "Copernican revolution" became fully accepted.

The English physicist and mathematician Isaac Newton (1642-1727) was one of the greatest figures in the scientific revolution of the 17th century. In mathematics he was the discoverer of the infinitesimal calculus, and in mechanics his three laws of motion, the basic principles of modern physics, led to the formulation of the law of universal gravitation. He erected a model of the universe which, in the words of the scientific historian J. Bronowski, "ticked on without a hitch for about two hundred years"; until, just after 1900, "time and light began to go awry" and Einstein asked himself "What would the world look like if I rode on a beam of light ?"

***Photo 1. Empedocles examining the Universe,* by the 15th-century Italian painter Luca Signorelli**
Photo © Alinari, Florence

***Photo 2.* Sun, moon and planets turning around the earth in the Ptolemaic system. Engraving by Cellarius (1661)**
Taken from *Harmonia macrocosmica* by Andreas Cellarius, Amsterdam, 1961.

***Photo 3.* The Copernican system. A new astronomical vision of the universe**
Photo © Bibliothèque Nationale, Paris.

***Photo 4.* Contemporary cartoon satirising Newton's theory of gravitation**
Photo John Freeman Group © British Museum, London.

to this idea by the Michelson experiment (1881) and the Michelson-Morley experiment (1887). At this time it was widely accepted that light moved about in an absolutely motionless medium, the ether; and that it should be possible to show the earth's motion through this ether. It is unnecessary to go into Michelson's experiment in detail here. Suffice it to say that he was working on light beams and that what he hoped to show was the influence exerted on them by the "ether wind".

But this hope failed to materialize as the mysterious ether proved impossible to detect. The empiricist interpretation has it that it was this *experimental fact* that inspired Einstein; by making a broad generalization from it he was able to establish that light always travelled at the same speed (and was therefore outside the sphere of certain well-known laws of classical physics).

This interpretation is certainly debatable. First of all, it is clear that various interpretations could be put on Michelson's experiment. Thus the Dutch physicist Lorentz followed up a suggestion of the Irish physicist Fitzgerald and put forward an original explanation: "the ether wind" caused matter to *contract,* which prevented any verification of the expected light effects. This proves that the solution put forward by Einstein (the theory of the constancy of the speed of light) had not been strictly based on "facts".

Better still, we now know that Michelson's experiment was not a determinant in Einstein's approach: "I can't say for certain when I first heard of Michelson's experiment. I was not aware that it had any direct influence on me". He made this point time and time again: "Michelson's experiment played no part, or at least no decisive part, in my personal struggle". On the other hand, we can assume that some "subjective" influences intervened.

Einstein explains in his *Autobiographical Notes* that for ten years he pondered a paradox which he had spotted at the age of sixteen. It was a kind of "thought experiment" in which he asked himself this question: what would happen if I pursued a beam of light while I myself was travelling at a speed equal to the speed of light? He suggested the following reply: "I would observe this beam as an oscillatory electromagnetic field at rest".

But for more reasons than one he considered this to be impossible; and for him this was a problem, an exciting paradox. "We see", adds Einstein, "that the germ of the special theory of relativity is already present in this paradox". This confirms that Einstein had been mentally prepared for some time to manipulate some basic problems in order to get certain concepts to work.

Naturally, he was conversant with the results of various experiments. He thought that, generally speaking, physics should be developed in contact with experiment and validated by it as far as possible. But the theory of relativity was not conceived in order to resolve the difficulties arising out of a particular experiment. It was the outcome of a much more general and much more theoretical development.

It was another problem that gave birth to special relativity: *the lack of symmetry of action* between electrical conductors and magnets. In fact if we use the Scottish physicist James Clerk Maxwell's theory of electricity and magnetism we have to resort to two different interpretations to explain what happens: 1) when a conductor is moved in relation to a magnet at rest and 2) when the same magnet is moved in relation to a conductor at rest. For Einstein this was nothing less than scandalous. In an unpublished manuscript he wrote that he found this asymmetry "intolerable". We must remember, however, that Maxwell's theory takes into account the results of experimentation.

But Einstein is guided by aesthetic conviction: since in reality the only thing that counts is the relative motion of the magnet and the conductor, the theory must also be symmetrical. The first sentence of the 1905 article is quite explicit: "We all know that Maxwell's electrodynamics, as understood today, when applied to a body in motion, leads to asymmetries which do not appear to be inherent in the phenomena".

This brings us once more to Einstein's "subjectivity", to his need to find (and at any rate postulate) a harmonious order in the universe. He repeatedly resorted to aesthetic considerations to work out his theoretical conceptions. For that is what "cosmic religion" is all about: it demands as elegant an explanation as possible (that is, with as few basic statements as possible) of the largest possible number of phenomena. So Einstein's "rationalism" is very deeply rooted; it is nurtured and guided by personal ideas, personal images and personal emotions.

To a question put to him by Jacques Hadamard during an investigation on invention in mathematics, Einstein replied: "Words and languages, whether spoken or written, seem to play no part in my thought process. The psychic entities which serve as elements to thought are reasonably clear signs or images which can be reproduced and combined 'at will'. There naturally exists a certain relationship between these elements and the logical concepts involved". In his *Autobiographical Notes* Einstein returned to the subject: "In my opinion, there is no doubt that our thought functions mostly without using signs (words) and that, what is more, it functions unconsciously for the most part."

The implications of such observations are wider than are at first apparent. In fact, it could well be that the use of "thought in images" was effective in helping Einstein to think out the concepts of time and space in an original way. This statement certainly has the merit of going straight to the point: "I sometimes wonder how it is that I was the only person to develop the theory of relativity? I think the reason is that a normal adult doesn't bother about problems posed by space and time. He assumes that he has known all he knows about it from infancy. But I, on the contrary, developed so slowly that I only began to ask myself questions about time and space after I was grown up. As a result, I was able to go more deeply into the heart of the problem than a child who had developed normally would have done." In other words, it is a stroke of luck that, as his biographers confirm, Albert Einstein as a child experienced difficulty in speaking.

Deep down, what did the baby Einstein's refusal to speak indicate if not resistance to certain cognitive schema imposed by

Zurich as it was in the early years of this century when Einstein was a professor there.

Photo © Zurich City Archives

society? A "successful" education is an education which makes people accept as natural a number of concepts about, and interpretations of, "reality". So it is also by definition an education which makes those who receive it conform; and which deprives them of the possibility of challenging the generally implicit presuppositions which are the basis of the knowledge it transmits.

Another idea dear to Einstein was that certain difficulties presented by a cognitive system can only be resolved if the more or less arbitrary and fortuitous bases for the system are first grasped. A mind that has been too well socialized and too well moulded cannot have the necessary detachment. So the critical approach which gave birth to the theory of relativity was only possible thanks to true intellectual autonomy. From this point of view, it is important to emphasize that Einstein had adopted an attitude of detachment with regard to generally accepted ideas. In his own words, he had arrived at "positively fanatical free thought", which manifested itself in the form of "suspicion of all forms of authority and scepticism about convictions in vogue in any social context".

Various historians have also observed that, in his youth, Einstein lived in an atmosphere that did not encourage intellectual conventionalism. He received his higher education at the Zurich Polytechnic, and he was working in the Berne Patent Office when he wrote his 1905 article on relativity. At this time, Switzerland "was opening its doors to a cosmopolitan crowd of students, émigré revolutionaries and young people who had fled national or social oppression rampant in their countries". Zurich around 1900 was "a huge permanent club".

Let us mention some important names: Rosa Luxembourg, George Plekhanov, Mussolini, Karl Radek, Lenin. Discussions were as numerous as they were heated; and not only about politics, but about epistemology and psychoanalysis. Einstein was fond of describing himself as a "heretic", and these details about his life help us understand the theoretical daring which enabled him to put forward such novel ideas.

Before we close, let us look at the problem posed by the now commonplace expression: theory of relativity. Few labels have inspired so many misconceptions—as if this relativity had anything to do with relativism or subjectivism. In fact, it would be better to talk, as Minkowski suggested, of the "postulate of the absolute world". This would be less misleading.

True, according to Einstein's theory, our measurements of space are relative, as are our measurements of time. Which means that they depend on the observer's point of view; and that there is no such thing as a privileged observer. But the famous "space-time" is in itself something absolute; it expresses in theoretical form the existence of a "reality" which is not directly accessible, but in relation to which all individual ("local") observations take on specific significance.

The expression "theory of relativity" does not in fact appear in the title of Einstein's works prior to 1911. He preferred to speak about "theory of invariants" (*Invariententheorie*) and, in 1928, he said that the theory of relativity would be more accurately called "theory of covariance" (that is, the principle that demands that all basic equations keep the same form in all systems of reference).

Why then did he finally agree to a label that was misleading, to say the least? Doubtless, even here psychological factors played their part. To speak of "relativity" is to recall that the Newtonian absolutes were dead; there is no absolute space, there is no absolute simultaneity. This label underlined the mutation worked out by Einstein, a mutation which many scientists and laymen considered "revolutionary". As the historian L.S. Feuer put it, the word relativity is in keeping with the spirit of the time and, more precisely, with the spirit that was at large in Zurich and in Berne.

■ **Pierre Thuillier**

The frontiers of science

by Arkadii B. Migdal

THE transformation of an idea into an accepted scientific truth, of a hypothesis into a rigorously formulated physical law, is a long and often tortuous process. But is it possible to retrace the various steps in this process? And what exactly is the difference between the scientific assessment of a phenomenon and the comprehension of it that common sense dictates?

ARKADII B. MIGDAL, *noted Soviet theoretical physicist, is a member of the USSR Academy of Sciences and adviser to the Academy's Landau Institute of Theoretical Physics. A specialist in the field of the theory of elementary particles and atomic nuclei, he is the author of over 150 scientific papers and five longer studies. His* Qualitative Methods in Quantum Theory *was published in the USA in 1977 by Benjamin-Cummings Publishing Co., Menlo Park, California.*

The first step in any scientific undertaking is to draw up the boundaries which mark off the area of indisputably established scientific truths from the area of "impossibilities" which conflict with the data yielded by repeated scientific experiment. Between the two lies a no-man's-land embracing phenomena which have not been studied but which, *a priori,* seem to lie within the bounds of the possible.

In our time the frontiers of the possible have been pushed back so far that they merge into those of wonderland. Men circle the earth in spacelabs for months at a time. Televiewers can watch a sporting event while it is taking place thousands of kilometres away. Equally miraculous, computers can play chess, translate, write verse and above all carry out in a matter of minutes calculations which would otherwise take years.

It is tempting to ask whether science knows its limits, and to wonder whether a scientific revolution may not lie ahead, which will turn our ideas upside down. The history of science and epistemology rule out the possibility of such an upheaval.

Even the astonishing concepts of the theory of relativity did not constitute a total revolution; they were a consequence of scientific evolution, solidly based on earlier scientific discoveries. Furthermore, they only affected a relatively limited number of problems and did not change the existing laws of mechanics and the electrodynamics of bodies moving at normal speeds.

What happened was that our knowledge was extended in the then unstudied field of speeds near to that of light. Before the theory of relativity was developed, it was logical to suppose that the laws of mechanics and electrodynamics were valid ▸

at speeds higher than those for which they had been established experimentally.

Doubts only emerged when this hypothesis was contradicted by scientific experiments. This is the usual path of scientific progress.

Science, it has been said, is the product of truth multiplied by doubt. At the beginning of the nineteenth century, descriptions of meteors, "celestial stones", were dismissed by many scientists as the fruits of fantasy. Stones, after all, could not drop from the sky. Such a refusal to accept the inexplicable is highly dangerous and often leads to error.

Many examples could be cited of the way in which preconceived opinions have slowed the development of science. The illustrious inventor of the theory of relativity himself made a mistake of this kind, drawing a false conclusion from a preconceived idea when he attempted to establish an entirely new cosmology.

After demonstrating that the laws of Euclidian geometry were not valid in the vicinity of a large mass, Einstein wished to take a new and staggeringly audacious step forward. He applied his theory of the gravitational field to the universe, replacing, as is the practice in the study of a gas, the real distribution of masses in space with the notion of the average density of matter.

It transpired that the equations of gravitation for a universe such as ours did not admit a static solution. To achieve a solution corresponding to his description of a finite universe whose radius of curvature was independent of time, Einstein artificially introduced into the gravitational equations an additional factor which upset their harmony.

Around the same time, an outstanding Petrograd mathematician named Alexander Friedmann was studying various possibilities of solving Einstein's equations without introducing this new factor. He came to the conclusion that the universe is expanding and that beside the "closed" model, there can exist for certain values of average mass density, an "open" model in which the dimensions of the universe increase indefinitely. At first Einstein was critical of Friedmann's work, but later came round entirely to his position and rejected the introduction of an additional factor in the gravitation equations.

"After reading Friedmann's letter, which Mr. Krutkov [a famous Soviet theoretical physicist] communicated to me", wrote Einstein, "I am now convinced that my criticisms were based on an error of calculation. I consider that Friedmann's results are correct and throw a new light on the question." Friedmann learned of the existence of this text shortly before his premature death in 1925. His solution was later confirmed experimentally when the U.S. astronomer Edwin Hubble demonstrated that the galaxies appear to be moving away from each other.

Several cases of scientific error have been analysed and methodological conclusions drawn from them, the most unassailable being that scientists should avoid taking up categorical positions in insufficiently studied fields. When scientific errors occur today, they are soon rectified.

Science does not, however, confine itself to defining the bounds of the possible, it also rigorously sorts out hypotheses, even the most likely ones, from demonstrated propositions. In this way it draws attention to propositions which require further research. It is possible to believe, for example, that the earth has been visited by emissaries from another world, but scientists have no grounds for affirming that this is so.

This weeding out process, disagreeable though it may often be for the scientist, has the effect of highlighting certain phenomena which though apparently strange are in fact real. Such a phenomenon is the "twin paradox". According to the theory of relativity, if one of a pair of twins were to go on a journey in a spaceship travelling at a speed approaching that of light, when he returned he would be younger than his brother who had remained on earth. This astonishing affirmation has been demonstrated not only theoretically but experimentally. Time measured during a space flight by a high-precision atomic clock is less than that shown by an identical clock which remains on earth.

Here is another example of a peculiar phenomenon which is nevertheless authentic. It has always been thought that marine animal and plant life only exist near the ocean surface where the sunlight can penetrate and make photosynthesis possible. However, volcanic areas of seabed, inaccessible to sunlight, have recently been discovered several kilometres beneath the surface where temperatures are high and in which specific forms of animal and plant life subsist, possibly as a result of processes of chemical synthesis.

It cannot be said of such phenomena that "I'd like to believe in them but there are no grounds for doing so". The expression "no grounds" signifies that the question has been studied and that initial conjectures have turned out to be unjustified. To put the scientific approach into a nutshell: "one would like to believe" in a given proposition, but if "there are no grounds" for doing so then it must be rejected.

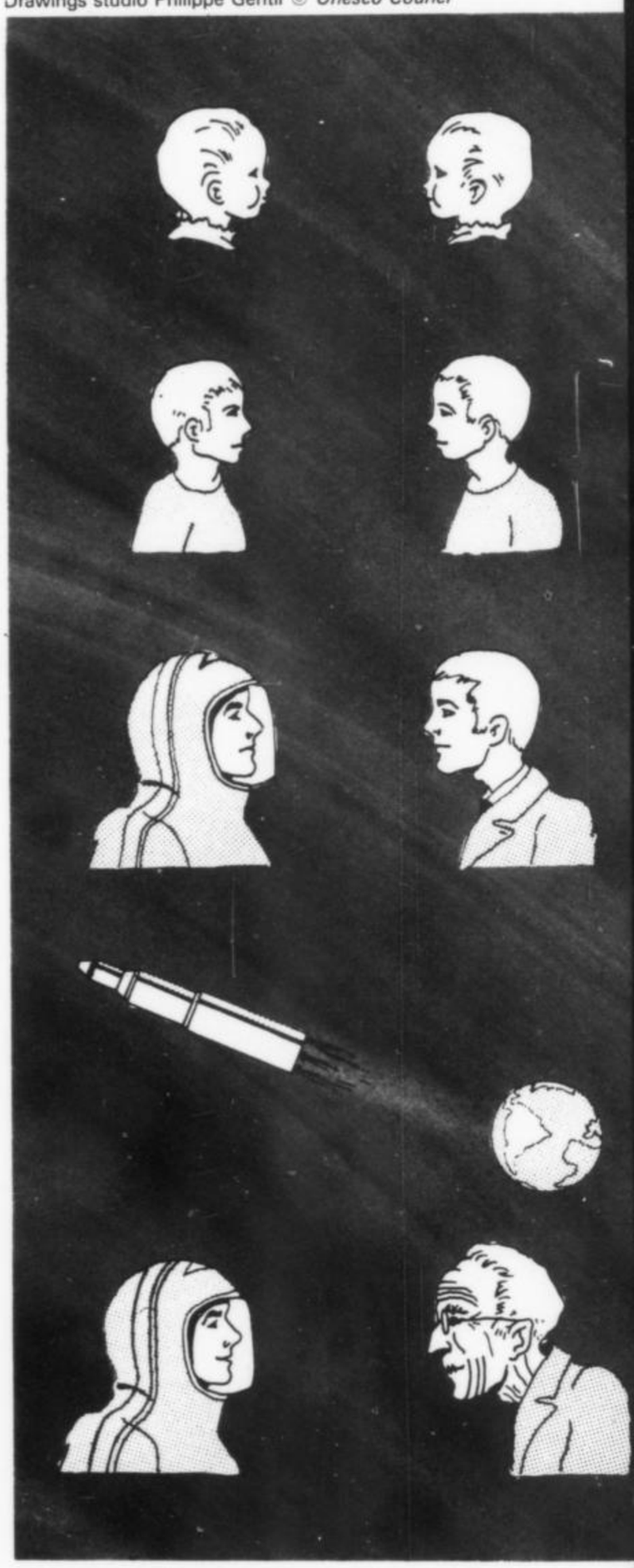
Human nature is such that mankind spontaneously aspires, not only to the beautiful but also to the mysterious and the unusual. In Pushkin's words, "an illusion which exalts us is dearer than the shadows of shabby truths". I would add to Pushkin's words the following remark by Einstein: "The most beautiful thing that we can experience is the mysterious". For Einstein the sense of mystery lies at the root of the fundamental tendencies of art and science. Alas, the same aspiration towards the mysterious is at the origin of much unscientific thought.

The task of science is to select the most likely explanations and to stick to them until experimental results demand that others be found. This does not mean that there should be an embargo on research into unlikely phenomena. As the U.S. physicist Richard Feynman pointed out: "One of the surest ways to stop scientific progress is to limit experimentation to fields in which the laws have already been discovered".

The following hypothesis, which is both simple and convincing, was adopted by science long ago. The processes which operate in nature are governed, in the last analysis, by the same laws which govern interactions in experimental physics. Until

The twin

Drawings studio Philippe Gentil © *Unesco Courier*



now this hypothesis has never been disproved; in fact it has shown itself to be so fertile that it has explained such a mysterious phenomenon as heredity.

The different branches of the exact sciences have many procedures in common. Methods exist, for example, which can prove an idea to be false even before research into it is begun. But the most important factor, without which success will elude even the most brilliantly gifted scientist, is the capacity for enthusiasm and astonishment at even the smallest achievement, and for approaching science with the veneration Einstein described when he wrote: "Full of astonishment, I simply make conjectures about mysteries and humbly try to paint a mental picture, which is far from being complete, of the perfect structure of the being".

■ **Arkadii B. Migdal**

paradox

The assertion of the relativity theory that time and distance are not absolute values, but are dependent upon the relative motion of observers, and that the only absolute constant is the speed of light leads to some apparently very bizarre conclusions about events occurring at ultra-high speeds. For example, to a man standing on a launching pad and watching a spacecraft moving away at a speed approaching that of light, a clock in the spacecraft (if he could see it) would appear to be moving very slowly. To the space-traveller looking back it would be time on earth that appeared to be slowed down. This apparent contradiction gave rise to a famous brain teaser known as the "twin paradox". If the man on the ground and the space-traveller were twins, what difference, if any, would there be in their ages on the return of the spacecraft to earth ? Ultra-high-speed travel, it seems, helps to keep you young. Einstein showed that, because of other relativistic effects, including, for instance, the effect of acceleration on the space-travelling twin involved in turning the spacecraft and bringing it back to earth, the astronaut would age more slowly than his stay-at-home twin. The English astrophysicist Herbert Dingle, however, maintained that this conclusion was absurd. If, as the theory of relativity states, there is no absolute movement, only movement in relation to other objects, it could be argued that the spacecraft had remained motionless and that the earth had moved away from it at great speed and then returned. In this case the earthbound twin would be the younger. But, obviously, both brothers cannot be younger than each other. There is, however, a fundamental difference between the relative movement of the astronaut twin and that of the stay-at-home. If the earth were said to move away from the spacecraft, the entire universe would have to move with it. In other words, the earth would remain motionless in relation to the universe and the relativistic effects associated with acceleration would still only apply to the twin in the spacecraft. So after all high speed travel *does* keep you young.

Photo © I.P.S., Paris

Albert Einstein and Robert Oppenheimer. In 1943 Oppenheimer was appointed director of the Los Alamos Atomic Research Laboratory where the first nuclear bomb was developed, and in 1947 became director of the Institute for Advanced Study at Princeton. "Einstein is often blamed or praised or credited with these miserable bombs," Oppenheimer wrote. "It is not in my opinion true... His part was that of creating an intellectual revolution, and discovering more than any scientist of our time how profound were the errors made by men before them... Einstein himself is really not answerable for all that came later."

The scientist's dilemma

by Albert Einstein

WE are living in a period of such great external and internal insecurity and with such a lack of firm objectives that the mere confession of our convictions may be of significance even if these convictions, as all value judgements, cannot be proven through logical deductions.

There arises at once the question: should we consider the search for truth—or, more modestly expressed, our efforts to understand the knowable universe through constructive logical thought—as an autonomous objective of our work? Or should our search for truth be subordinated to some other objective, for example to a "practical" one? This question cannot be decided on a logical basis. The decision, however, will have considerable influence upon our thinking and our moral judgement, provided that it is born out of deep and unshakeable conviction. Let me then make a confession: for myself, the struggle to gain more insight and understanding is one of those independent objectives without which a thinking individual would find it impossible to have a conscious, positive attitude towards life.

It is the very essence of our striving for understanding that on the one hand, it attempts to encompass the great and complex variety of man's experience, and that on the other, it looks for simplicity and economy in the basic assumptions. The belief that these two objectives can exist side by side is, in view of the primitive state

of our scientific knowledge, a matter of faith. Without such faith I could not have a strong and unshakeable conviction about the independent value of knowledge.

This, in a sense, religious attitude of a man engaged in scientific work has some influence upon his whole personality. For apart from the knowledge which is offered by accumulated experience and from the rules of logical thinking, there exists in principle for the man in science no authority whose decisions and statements could have in themselves a claim to "Truth". This leads to the paradoxical situation that a person who devotes all his strength to objective matters will develop, from a social point of view, into an extreme individualist who, at least in principle, has faith in nothing but his own judgement. It is quite possible to assert that intellectual individualism and the thirst for scientific knowledge emerged simultaneously in history and remained inseparable ever since.

Someone may suggest that the man of science as sketched in these sentences is no more than an abstraction which actually does not exist in this world, not unlike the *homo oeconomicus* of classical economics. However, it seems to me that science as we know it today could not have emerged and could not have remained alive if many individuals, during many centuries, had not come very close to the ideal.

Of course, not everybody who has learned to use tools and methods which, directly or indirectly, appear to be "scientific" is to me a man of science. I refer only to those individuals in whom the scientific mentality is truly alive.

What then, is the position of today's man of science as a member of society? He obviously is rather proud of the fact that the work of scientists has helped to change radically the economic life of men by almost completely eliminating muscular work. He is distressed by the fact that the results of his scientific work have created a threat to mankind since they have fallen into the hands of morally blind exponents of political power. He is conscious of the fact that technological methods, made possible by his work, have led to a concentration of economic and also of political power in the hands of small minorities which have come to dominate completely the lives of the masses of people, who appear more and more amorphous. But even worse: the concentration of economic and political power in the hands of a few has not only made the man of science dependent economically, it also threatens his independence from within; the shrewd methods of intellectual and psychic influences which it brings to bear will prevent the development of independent personalities.

Thus the man of science, as we can observe with our own eyes, suffers a truly tragic fate. Striving in great sincerity for clarity and inner independence, he himself, through his sheer superhuman efforts, has fashioned the tools which are being used to make him a slave and to destroy him also from within. He cannot escape being muzzled by those who have political power in their hands. As a soldier he is forced to sacrifice his own life and to destroy the lives of others even when he is convinced of the absurdity of such sacrifices. He is fully aware of the fact that universal destruction is unavoidable since historical development has led to the concentration of all economic, political and military power in the hands of national States. He also realizes that mankind can only be saved if a super-national system, based on law, would be created to eliminate for all time the methods of brute force. However, the man of science has slipped so much that he accepts the slavery inflicted upon him by national States as his inevitable fate. He even degrades himself to such an extent that he helps obediently in the perfection of the means for the general destruction of mankind.

Is there really no escape for the man of science? Must he really tolerate and suffer all these indignities?

Is the time gone for ever when, aroused by his inner freedom and the independence of his thinking and his work, he had a chance of enlightening and enriching the lives of his fellow-human beings? In placing his work too much on an intellectual basis, has he not forgotten about his responsibility and dignity? My answer is: while it is true that an inherently free and scrupulous person may be destroyed, such an individual can never be enslaved or used as a blind tool.

If the man of science of our day could find the time and the courage to think honestly and critically over his situation and the tasks before him and if he would act accordingly, the possibilities for a sensible and satisfactory solution of the present dangerous international situation would be considerably improved.

■ **Albert Einstein**

This article is a slightly abridged version of a message read before the forty-third meeting of the Italian Society for the Advancement of the Sciences in 1950.

Relativity and the atom

According to the relativity theory, the mass of an object increases with its velocity (see drawing page 14). In the everyday world velocities are much too low for us to notice the effects of relativity, but in the world of the atom smasher, or nuclear accelerator, relativistic effects become very noticeable indeed. Atom smashers are huge machines in which atomic particles are accelerated to fantastic speeds. At the Linear Accelerator Center at Stanford, California (aerial view, right) electrons are accelerated so close to the speed of light that their mass is increased 40,000 times. At the end of the 3,050-metre-long installation is a storage ring where the particles are smashed into one another, creating new matter. Scientists can observe colliding particles in detail using a "bubble chamber" containing a special superheated liquid under pressure. The particles, which are too small to be seen are shot through the liquid and create strings of tiny bubbles which, when photographed, enable scientists to measure the mass and other properties of the invisible particles. Top photo, far right, shows traces made by particles in the "Gargamelle" bubble chamber of CERN (European Council for Nuclear Research) in Geneva. Lower photo, view of "Gargamelle's" observation portholes. Accurate measurements can be made of the conversion of the energy of motion into matter and mass which confirm Einstein's famous equation expressing the equivalence of mass and energy, $E = mc^2$.

Photo Georg Gerster © Rapho, Paris

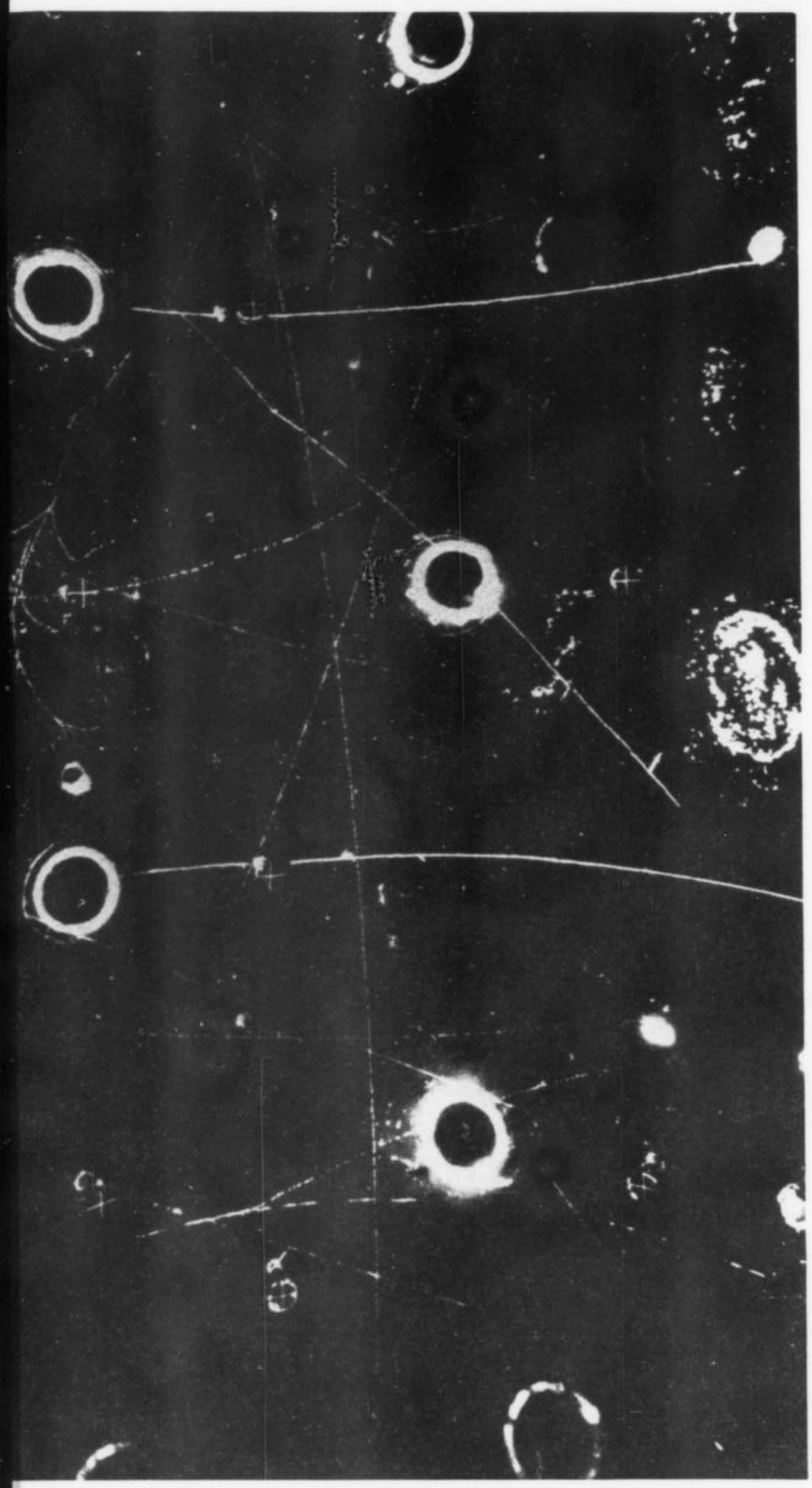
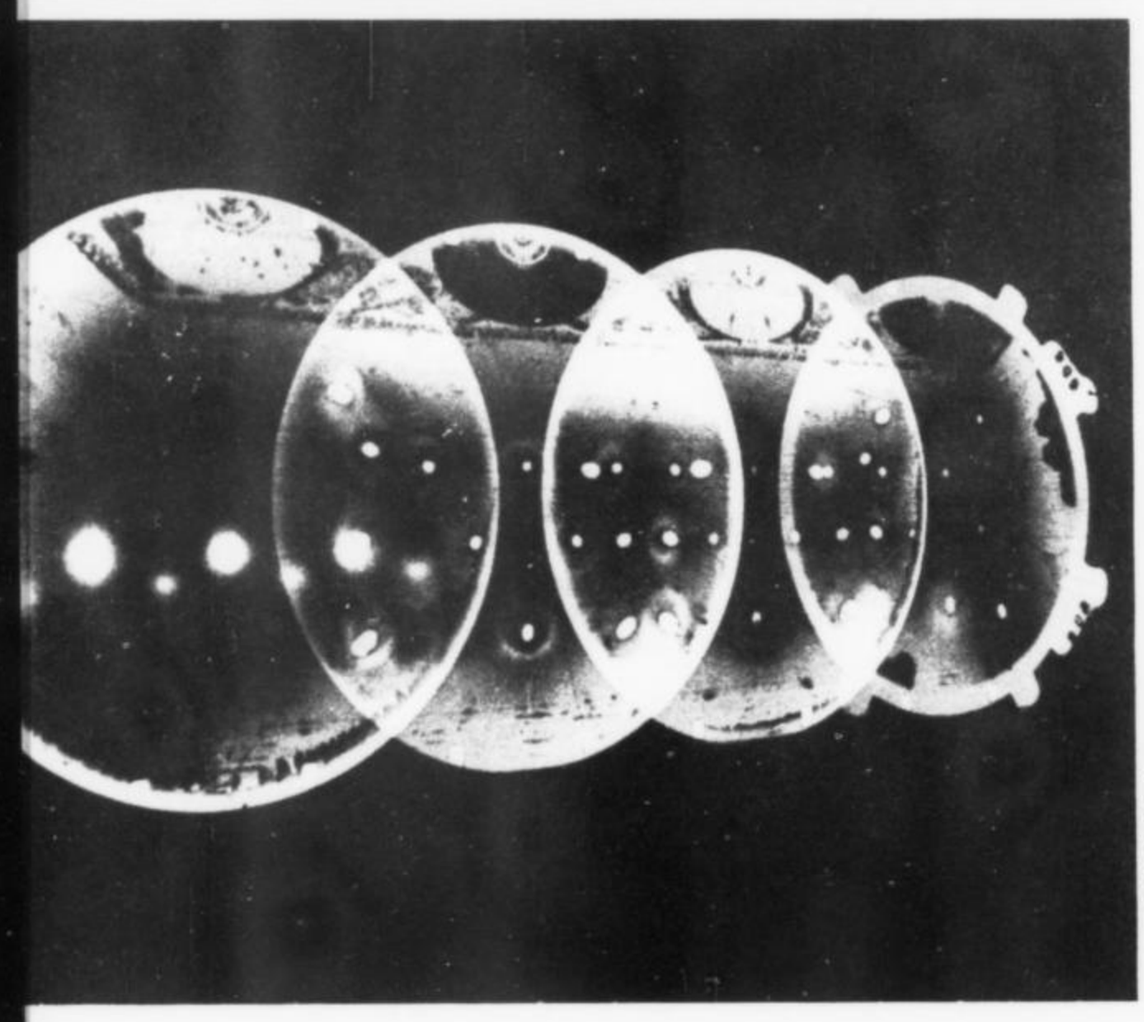


Photo © CERN, Geneva



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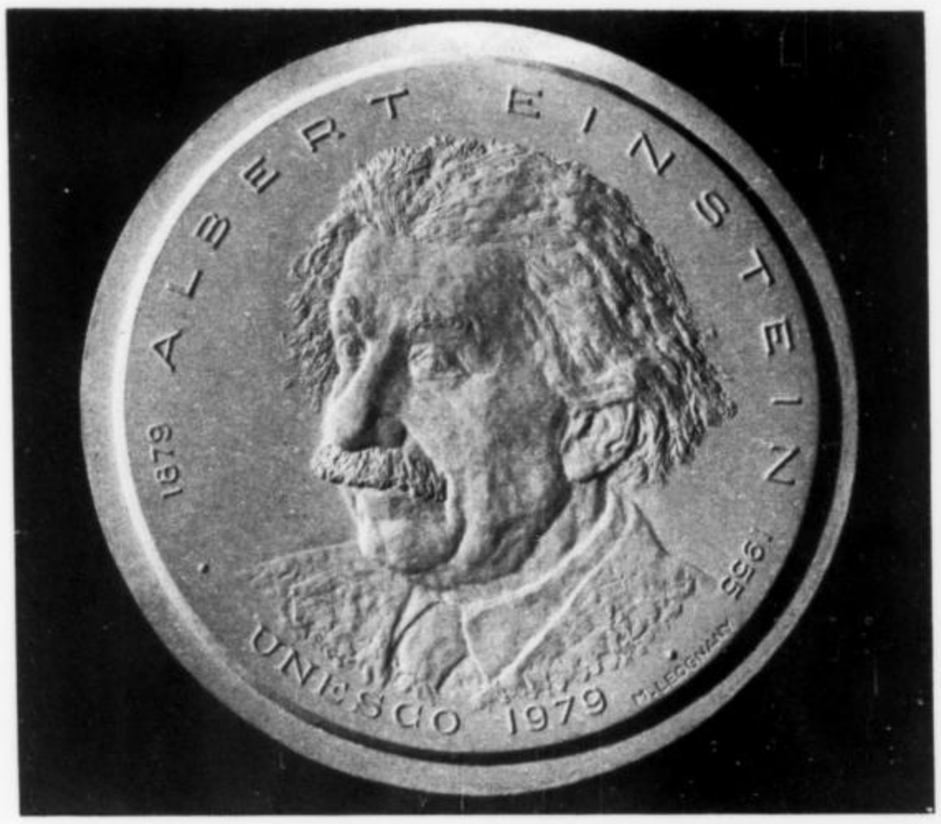

Unesco Medal for Einstein Centenary

To commemorate the hundredth anniversary of Albert Einstein's birth on 14 March 1879, Unesco has issued a medal minted in gold, silver and bronze. The work of the French engraver Max Léognany, the medal (above) shows on one side the scientist in his later years, with the inscription 1879 ALBERT EINSTEIN 1955 — UNESCO 1979. On the other side a silhouette of Einstein's head forms the background for three of the mathematical equations that sum up Einstein's essential contributions to physics. The best-known equation, $E = mc^2$, established a fixed, quantitative relationship between energy (E) and matter (m) as determined by the square of the speed of light. The second equation symbolizes the results of Einstein's research on the law of the photo-electric effect, for which he was awarded the Nobel Prize for physics in 1921. The third stems from his work on the theory of relativity. Einstein is the first man of modern times to be honoured in Unesco's "Anniversaries of Great Men" series, in which medals have already been dedicated to Aristotle, Michelangelo and Rubens. The medals, struck by the Paris Mint, are also available with a chain-ring for wear as jewellery. They can be obtained from : the Philatelic and Numismatic Programme of Unesco, 7 Place de Fontenoy, 75700 Paris.

Photo Michel Claude, Unesco

Further reading on Einstein

Einstein: A Centenary Volume, edited by A.P. French. Published by Heinemann, London, for the International Commission on Physics Education, 1979. (Initiated by Unesco, the centenary volume project was carried out with Unesco co-operation and financial support).

Einstein's Universe, by Nigel Calder. Published by the British Broadcasting Corporation, 1979.

Albert Einstein and Relativity, by D.J. Raine, Priory Press Ltd., London, 1975.

Einstein and the Generations of Science, by Lewis S. Feuer, Basic Books, Inc., New York, 1974.

Relativity for the Layman. by James A. Coleman, Penguin Books, Harmondsworth, Middlesex, U.K. Revised edition 1969.

Relativity and Common Sense, by Hermann Bondi. Heinemann, London, 1965. Reprinted 1978.

The Einstein Century : Four Generations of Revolutionary Thought is the theme of Unesco's scientific quarterly **Impact of Science on Society, Vol. 29, No. 1 (Jan.-March 1979).**

The Ascent of Man, by J. Bronowski. British Broadcasting Corporation, 1973.

Stars, strings, shadows and spheres

Photo © Ullstein, Fed. Rep. of Germany

When Einstein was in Hollywood in 1931, Charlie Chaplin invited him and his wife to attend the première of the film *City Lights.* During the drive to the town they were recognized by the crowd and enthusiastically cheered. Chaplin calmly remarked to his guest : "The people are applauding you because none of them understands you and applauding me because everybody understands me."

Einstein playing the violin. Drawing by the Russian artist Leonid Pasternak (1862-1945)

Photo Studio Edmark © Mrs. Lydia Pasternak Slater, Oxford, U.K.

Genius in silhouette. Cut-outs of Einstein and his family made by the great man himself in 1919.

Taken from *Einstein, A Centenary Volume,* edited by A.P. French, Heinemann Educational Books Ltd., London

Photo © Francis Everitt, BBC, London

Scientists today are using high-precision engineering to test Einstein's theories to increasingly accurate limits. Here, a perfectly round (to within a millionth of an inch) sphere of quartz the size of a tennis ball is being checked at Stanford University in California in preparation for an ingenious test of General Relativity. Sometime in the 1980s four such spheres will be set spinning as gyroscopes in a spacecraft orbiting the earth. The experiment is designed to detect the very slight dragging of space by the rotation of the earth.

BRODARD GRAPHIQUE. COULOMMIERS. — Dépôt légal C 1 — Mai 1979 — IMPRIMÉ EN FRANCE *(Printed in France).*

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news from unesco

Scientists Note Gradual Progress in Earthquake Predictions

Although gradual progress has been made in improving earthquake prediction, scientists still do not have a general theory to explain why an earthquake occurs in a particular place at a particular time.

Nor, said the chairman of a Unesco symposium on the subject, can they predict with much accuracy the magnitude of earth tremors. Nevertheless, he added, many lives have been saved through successful predictions in past years, especially in China, and "the experience and the success of China in this field is one of the main causes for optimism that effective earthquake prediction will be possible elsewhere."

Dr. Frank F. Evison, of the Institute of Geophysics, Victoria University of Wellington, New Zealand, was speaking at a press conference during a week-long International Symposium on Earthquake Prediction, held at Unesco Headquarters, Paris.

The progress which has been made in recent years, he suggested, has consisted in compiling additional observations and additional data concerning about 15 types of earthquake "precursors" — natural phenomena and anomalies which had already been known to precede major earthquakes.

"The situation at present," he said, "is that we're waiting to test out hypotheses about earthquake predictions. But this requires not only more observations and more data but more earthquakes taking place, unless and until a major theoretical breakthrough occurs."

Dr. Tsuneji Rikitake, of the department of applied physics of the Tokyo Institute of Technology, pointed out, however, that China had successfully predicted four out of five major earthquakes (those with a magnitude of more than 7 on the Richter scale) in the years 1975 and 1976. These "imminent" predictions

Photo Unesco - A. Vorontzoff

Frioul, Italy : damage from the earthquake of 6 May 1976.

(ranging from a few days to about 20 minutes) had enabled many lives to be saved in the case of one earthquake, at least. The others had occurred in sparsely settled regions of China.

Japan itself has a budget for earthquake prediction this year of some $ 36 million, according to Dr. Makane Simizu, of the office for earthquake prediction of the Science and Technology Agency, Tokyo. Furthermore it is spending about $ 3.5 billion a year for mitigation of earthquake hazards, including seismic engineering programmes. Japan has also developed sophisticated machinery for translating earthquake predictions into governmental decisions. Thanks to these procedures, an earthquake warning can be issued, if necessary, about two hours after the initial detection by scientists of a geodetic anomaly.

If progress has been gradual in earthquake prediction methods, however, research on the social and economic effects of earthquake predictions and warnings is only in its initial stages, said Dr. Ralph H. Turner of the Department of sociology of the University of California at Los Angeles.

"Developing earthquake predictions is only half the job," he said. "You have to know how to make the best use of them, and this is where social science research comes in. The effectiveness of earthquake prediction as a tool for reducing hazards depends upon developing community response plans that can be implemented when predictions are issued. The development of such plans depends in turn on understanding how individuals and groups will respond to the news of an earthquake warning."

Systematic research in this area began only about three or four years ago, Dr. Turner said. Before that, social scientists depended on what they knew about behaviour in other types of catastrophes. Even now, knowledge is quite incomplete and based mainly on studies in Japan and the United States.

What is known, however, "is enough to put to rest the more bizarre fears of mass panic and wildly irrational response to earthquake prediction. Most people tend to continue life as normal, whenever they can."

Communication Commission Studies Technology and Media Impact on Development

Communication media in India play an important role in promoting development objectives, but are biased toward politics (rather than economics), middle class interests, a male public and the urban population.

This emerged from a discussion by Indian specialists at a Unesco-sponsored round-table discussion on communication and development in New Delhi in March. The round-table was held in conjunction with the fifth session of the International Commission for the Study of Communication Problems and members of the Commission also took part.

During a second round-table, on the theme of communication and technology, experts from Canada, India, Japan, USA, USSR and Yugoslavia presented papers on the implications of the technological revolution for communication.

The 16-member Commission, headed by the former foreign minister of Ireland, Mr. Sean MacBride, is preparing a final report for submission to Unesco by the end of this year. At its New Delhi meeting it gave particular attention to two papers prepared by members of the Commission : one by Mr Johannes Pieter Pronk of the Netherlands on the implications of the new international economic order on the diffusion of information ; and a paper by Mr. Elie Abel (USA) on "Communication for an interdependent, pluralistic world," which was discussed at length.

Mr. Abel's paper set out areas in which the Commission might take concrete decisions and other issues of political sensitivity which, it argued, were not likely to yield a consensus.

During the discussions it emerged that Commission members did not feel that communication technology was "value free" or neutral; questions like access, control, cost and manpower had to be taken into account. Members also expressed the view that the choice of technology could not be made by technicians alone without directions from governments. There was general agreement on the need to reduce telecommunication tariffs, to make access to communication satellite services easier and to bring about speedy transfer of technology from the rich to the poor nations.

Another topic discussed during the fifth session was the protection of journalists. This important subject was previously debated with some international jurists and journalists' organizations, leaving it to professional associations and interested circles to inform the Commission of the results of further consultations. Some members felt that no special protection was needed, others that the nature of the profession called for permanent guarantees.

The Commission decided to meet again from 4 to 8 June, when it will consider particularly the question of culture and communication, as well as continuing the debate on the outline of the final report.

Photo Unesco - Michel Claude

The Director-General addressing the United Nations Committee on the Elimination of Racial Discrimination. At the right is Mr. George O. Lamptey (Ghana), chairman of the committee.

Peace Depends on Ending Racism, M'Bow Tells U.N. Committee

World peace requires not only better understanding among nations and real disarmament but also a victory over poverty and racial and social segregation, the Unesco Director-General told a U.N. committee meeting at Unesco Headquarters.

Speaking at the opening of the 19th session of the United Nations Committee on the Elimination of Racial Discrimination, Mr. Amadou-Mahtar M'Bow declared that "nothing is more urgent than to mobilize the vital forces of all humanity to battle the scourges which menace mankind and to struggle against racism and racial prejudice, everywhere and in every way, so as to erase them from the memory of every child, every woman and every man."

Tracing the history of Unesco's action in this field, the Director-General noted that it had been given new impetus by the Declaration on Race and Racial Prejudice adopted by acclamation at the last General Conference of Unesco. The Declaration, he said, "constitutes a coherent synthesis of all the challenges raised by racism — biological, sociological and judicial, as well as cultural, political, economic and ethical. It constitutes a reference instrument all the more important since its moral force was enhanced by its unanimous adoption by the representatives of all Member States."

The main task of the Committee on the Elimination of Racial Discrimination is to examine reports from the 27 States which are parties to the International Convention on the Elimination of all Forms of Racial Discrimination. In addition, during its April meeting, it discussed methods of implementing the Unesco Declaration on Race and Racial Prejudice.

Symposium Urges Fund to Aid Third World Communication

Unesco has been urged to study the possibility of creating an international fund for the development of communication, the purpose of which would be to aid developing countries to improve their communication infrastructures.

The recommendation was one of several addressed to Unesco at the close of a week-long symposium on "The Right to Communicate", sponsored by the international non-governmental organizations with consultative status at Unesco. (A similar recommendation had been adopted by the Intergovernmental Conference on Communication Policies in Asia and Oceania last February in Kuala Lumpur.)

Representatives of some 70 organizations took part in the Paris meeting which consisted of a series of round-table discussions on such themes as languages and communication; diversified communication for diversified publics; feedback and participation; the right to communicate as a human right; and the new international communication order.

Another recommendation urged Unesco to consider launching an international scholarly journal in the communication field.

"Children" theme of Unesco Pavilion in Montreal

In honour of the International Year of the Child, the Unesco pavilion at the "Man and His World" exposition in Montreal this summer will be centered on the theme : "What kind of world are we leaving our children ?".

The pavilion, in which Unicef and the International Civil Aviation Organization are also co-operating, will be open from 21 June to 3 September. The central theme will be illustrated by a dramatized presentation of the world in the form of a geodesic globe designed by American architect and futurologist Buckminster Fuller. The same room will also contain an exhibition of children's toys from various parts of the world and an audio-visual show describing Unesco's work with children.

- Photo displays will illustrate other aspects of Unesco's programme while the cinema will show Unesco and Unicef films. In addition, there will be a special cinema for children in which children's films will be screened. Also on exhibit will be the winning designs from a children's drawing contest organized in more than 80 countries by Unesco, in collaboration with Unicef and the U.N. High Commissioner for Refugees.

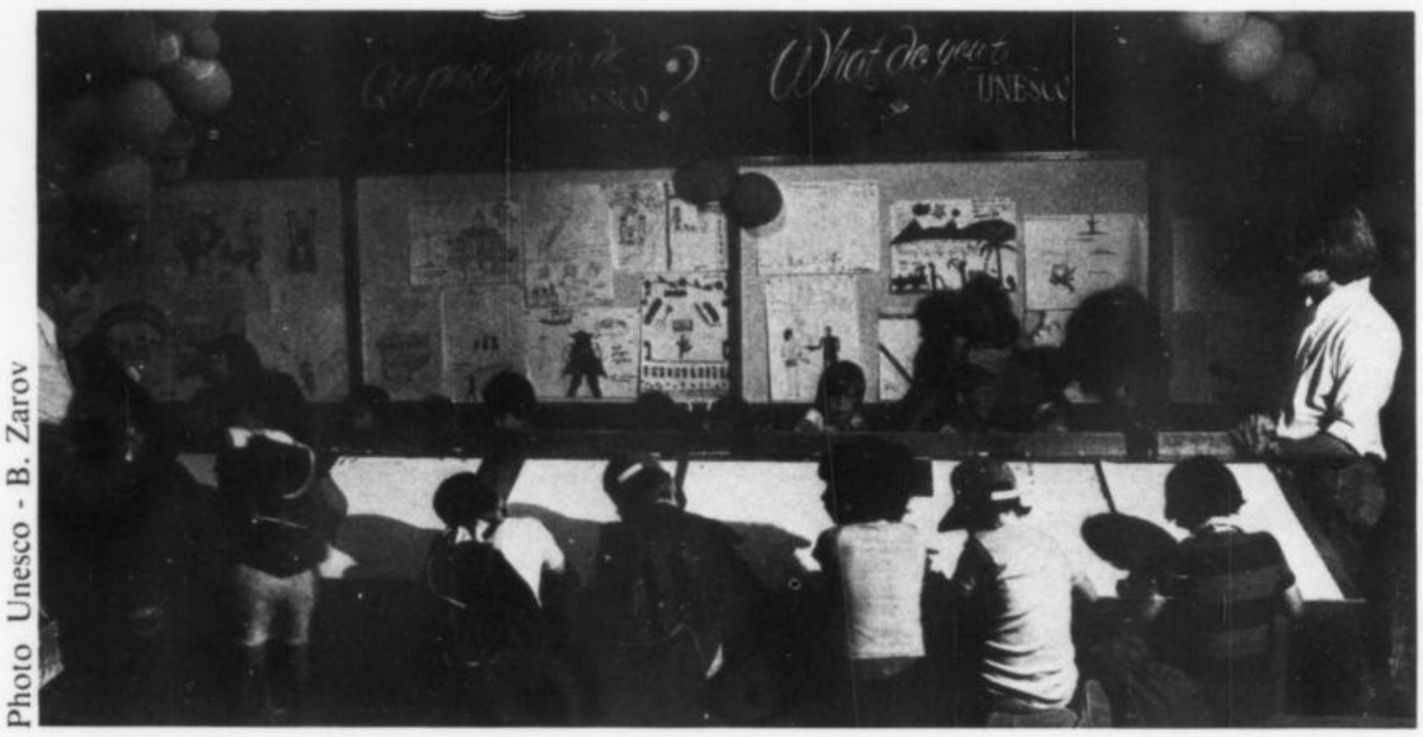


Photo Unesco - B. Zarov

The "children's corner" in the Unesco Pavilion at "Man and His World", 1978. This year the space will be enlarged and will cover more varied activities.

Homage to Korczak at Unesco

To celebrate the hundredth anniversary of the birth of Janusz Korczak, the permanent delegation of Poland to Unesco and the French association "The Friends of Janusz Korczak" organized an international week of homage to the famous educator and paediatrician from 2 to 12 April.

The week included an exhibition on "Korczak and the children" as well as an international symposium on the work of Korczak in the world of today and the training of educators. In addition, there was a projection of the film "Le Roi Mathias Ier", based on the novel by Korczak.

Born in Warsaw, Korczak (his real name was Henryk Goldszmit) died in 1942 in the Treblinka extermination camp after a life entirely devoted to children. Trained as a doctor, he became interested in the education of children through paediatrics. He was the author of a remarkable series of books about and for children.

Unesco Coupons : a new record

During 1978, more than $ 17,500,000 worth of Unesco Coupons were sold, setting a new record for this programme. Established in 1950, the Unesco Coupon Scheme enables countries to use non-convertible currencies in order to import educational, scientific and cultural equipment and supplies from abroad.

Turkish Professor Awarded Unesco Prize for Human Rights Teaching

Mr. Mumtaz Soysal, a professor at the University of Ankara and vice-president of the executive board of Amnesty International, has become the first winner of the Unesco Prize for Human Rights Teaching.

In announcing the award, Unesco Director-General Amadou-Mahtar M'Bow said Professor Soysal's activities extend far beyond his university and have made his life and work an example for the entire international community.

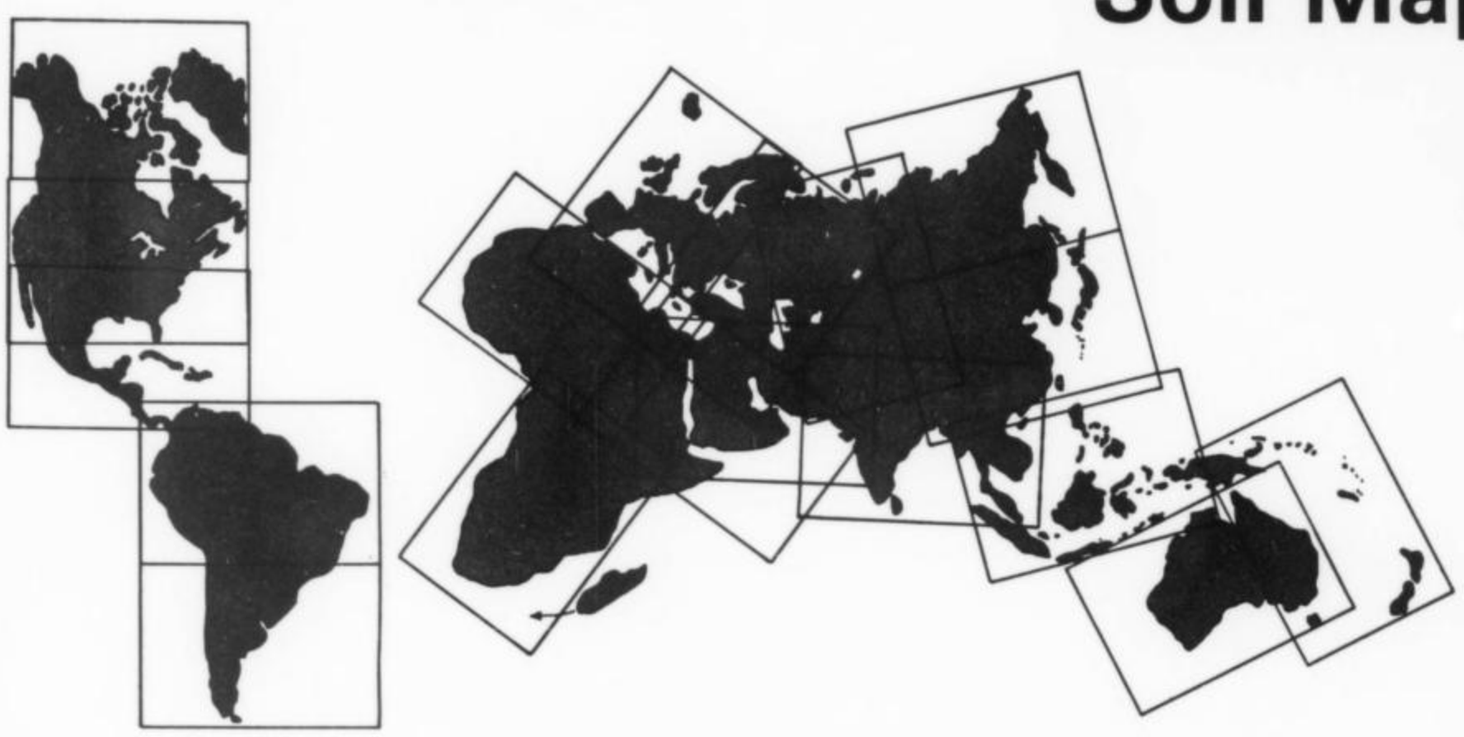
Mr. Soysal was nominated for the award by an international jury, headed by Prof. Shigeru Oda of Japan, a judge at the International Court of Justice. The jury also nominated for honourable mention Prof. Thomas Buergenthal (USA) and Maitre Louis Edmond Pettiti (France).

The Unesco Prize for Human Rights Teaching was created last year by the Executive Board of the Organization to mark the 30th anniversary of the adoption of the Universal Declaration of Human Rights.

BRODARD GRAPHIQUE, COULOMMIERS. — Dépôt légal C 1 — Mai 1979 — IMPRIMÉ EN FRANCE (Printed in France).

Just published by Unesco

Soil Map of the World



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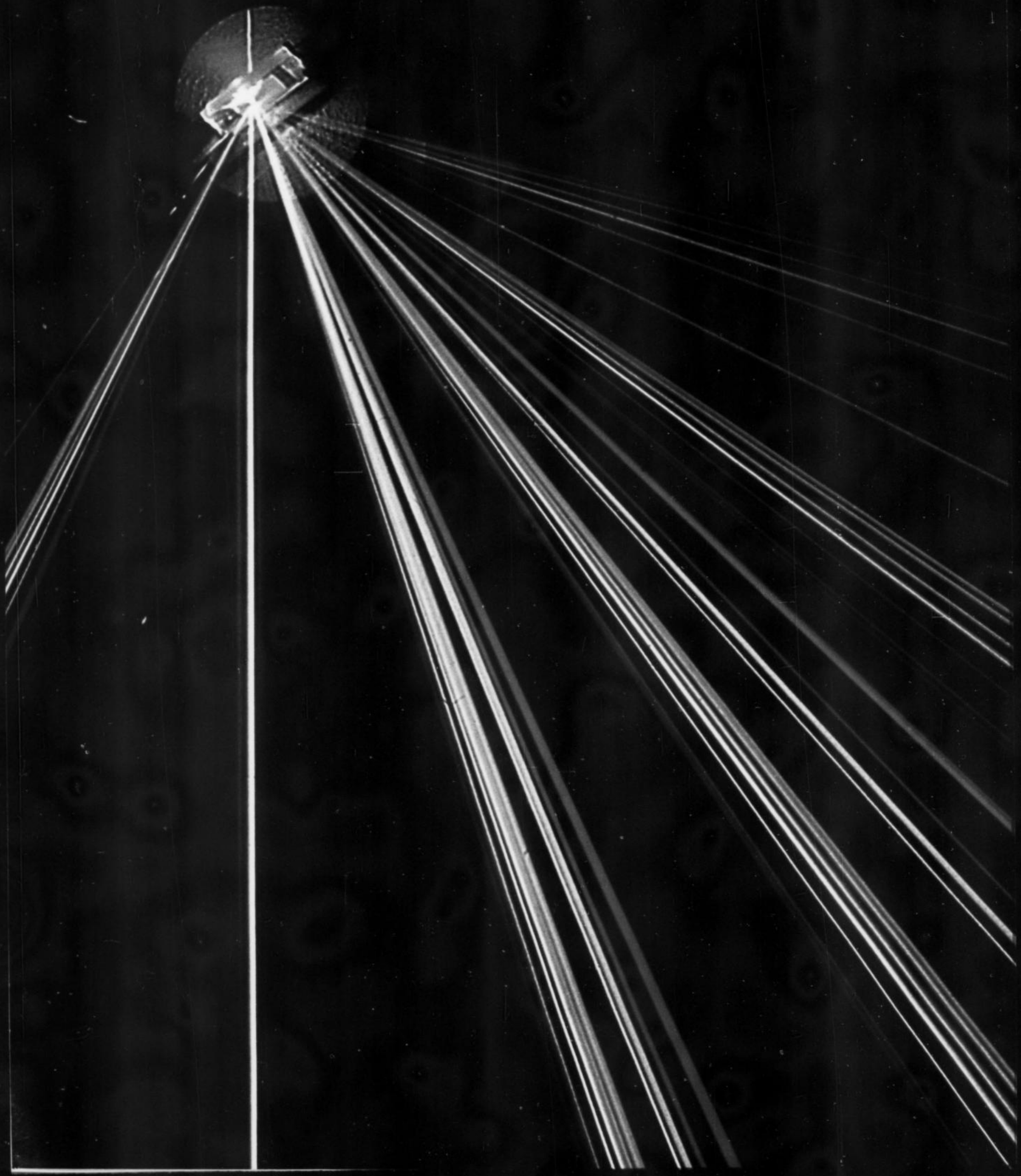
The light of genius

"In my opinion Einstein would be one of the greatest theoretical physicists of all time even if he had not written a single line on relativity", wrote the distinguished German physicist Max Born. In fact, Einstein was awarded the 1921 Nobel prize for physics, not for his relativity theories, but for a paper published in 1905 on the photo-electric effect in which he declared that light consisted of particles. And in 1916 he formulated the principles which were to lead, forty years later, to the development of the laser, a device capable of producing a light beam intense enough to vaporize the hardest and most heat-resistant materials. Among the many applications of the laser today are delicate eye surgery, the drilling of diamonds, making ultra-accurate measurements and producing holographic effects. Photo shows the scintillating light effects produced when a laser beam passes through a diffraction grating. Part of the beam is dispersed into its constituent colours; the remainder continues vertically down the side of the picture.

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